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COMPREHENSIVE ABATEMENT PERFORMANCE PILOT STUDY

VOLUME II: MULTI-ELEMENT DATA ANALYSES

Final Report

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AUTHORS AND CONTRIBUTORS

The study that led to this report was funded and managed by the U.S. Environmental Protection Agency. The study was conducted collaboratively by two organizations under contract to the Environmental Protection Agency, Battelle Memorial Institute and Midwest Research Institute. Each organization's responsibilities are listed below.

Battelle Memorial Institute (Battelle)

Battelle was responsible for the design of the study, for producing the design documentation and the Quality Assurance Project Plan, for developing training for the field teams, for recruiting cooperators for the study, for providing team leaders for the field teams, for auditing the field teams, for data management of combined study data, for auditing the study data, for identifying the elements that were selected for analysis, for conducting the statistical analysis of the data, and for writing the final report.

Midwest Research Institute (MRI)

Midwest Research Institute was responsible for participating in the planning for the study, for writing certain chapters and appendices in the Quality Assurance Project Plan, for designing and producing a vacuum device for collecting field samples, for developing training for the field teams, for providing the technicians who collected the field samples, for auditing the field teams, for conducting the laboratory analysis of the field samples, for identifying the elements that were selected for analysis, for managing the data associated with the field samples, for auditing the laboratory results, and for producing the multi-element data on which this report is based.

U.S. Environmental Protection Agency (EPA)

The Environmental Protection Agency was responsible for managing the study, for reviewing the design and the Quality Assurance Project Plan, for assessing the performance of the recruiters and the field teams, for reviewing audit reports, for reviewing draft reports and for arranging the peer review of the draft final report. The EPA Work Assignment Managers were Samuel Brown, Benjamin Lim, and John Schwemberger. The EPA Project Leader was John Schwemberger. The EPA Project Officers were Gary Grindstaff, Joe Breen, Jill Hacker, Phil Robinson, and Sineta Wooten.

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EXECUTIVE SUMMARY

This report presents the results of the statistical analysis of multi-element data collected during a pilot study that preceded the Comprehensive Abatement Performance (CAP) Study. The goal of the CAP Study was to assess the long-term efficacy of lead-based paint abatement. The pilot study was conducted to test the sampling and analysis protocols for the full study.

For the multi-element analysis, concentrations of lead, as well as of aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc in dust and soil samples were measured. Concentrations of barium, cadmium, chromium, titanium, and zinc were measured because these elements were regarded as possible constituents of paint. Concentrations of aluminum, calcium, magnesium, nickel, and potassium were measured because these elements were regarded as likely to be found in soil.

The multi-element analysis was undertaken to determine whether relationships among these elements could provide a "tracer" for identifying the sources and pathways of lead in households. Pilot study data were used to 1) characterize the concentrations of lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc samples in household dust and soil; 2) measure the differences in these concentrations associated with renovation and lead-based paint abatement; and 3) investigate the relationship among the elements by sample type (i.e., samples taken from different locations).

Dust and soil samples from six houses in Denver, Colorado were studied. Two houses were unabated (identified as relatively free of lead-based paint in Volume 1 of the CAP Pilot report (US EPA, 1995)). These houses were labeled as "relatively free of lead-based paint" because the lead loadings in paint usually did not exceed the criterion used to trigger abatement in the HUD Abatement Demonstration. The remaining four houses were abated using removal methods and/or encapsulation or enclosure methods. One house was abated using primarily removal methods on the interior and primarily encapsulation or enclosure methods on the exterior. Another house was abated using predominantly encapsulation or enclosure methods on the interior and predominantly removal methods on the exterior. The other two houses were abated by primarily the same method on the interior as the exterior (one removal, the other encapsulation or enclosure). Hence most of the lead levels in the paint in the houses studied were less than 1.0 mg/cm^2.

A total of 109 vacuum dust samples was collected. Between 16 and 22 dust samples were collected at each house from window channels (also called "troughs" or "wells"), window stools (often referred to as "sills"), air ducts, floors, bedcovers/rugs/upholstery, and entryways. A total of forty-eight (48) soil samples was collected. Eight samples were collected from each house: from just outside the front and back entryways, at different locations along the foundation, and at different locations on the property boundary.

All elements except for potassium and chromium had significant differences in concentration levels across sample types. Lead, barium, cadmium, calcium, magnesium, nickel, and zinc typically had higher concentration levels in dust samples than in soil samples. Aluminum and titanium generally had higher concentration levels in soil samples than in dust samples. Calcium was the element with the highest concentration in dust samples. Aluminum had the highest concentration in soil samples.

Tests of hypotheses on the differences due to abatement and renovation resulted in far more cases of significance for renovation than for abatement. There were thirteen (13) cases of significant differences for renovation, considerably more than the number of cases that would be expected by chance alone. For renovation effects, there were several cases of significantly higher levels in interior dust for lead and for the elements calcium, magnesium, and nickel. Also for renovation effects, there were cases of significantly lower concentrations in soil sample types for the elements aluminum, titanium, and potassium. For abatement effects, the number of cases of significance was equal to the number that would be expected by chance alone. Significantly higher concentrations of lead and zinc were the case for exterior entryway samples and lead was significantly higher in interior entryway samples.

After controlling for differences between houses with different abatement and renovation history, relative concentrations of the elements suggested the following grouping of sample types in unabated, unrenovated houses: 1) boundary, foundation, and entryway soil samples, and 2) entryway dust and bedcovers/rugs/upholstery, along with floors and window stools. Window channels and air ducts did not appear similar to other sample types or each other. For renovated houses, the three soil samples could be grouped together, and there were similarities between floor and entryway dust samples, and to a lesser extent, between window channels and window stools. For abated houses no groupings were clearly apparent.

Other approaches were used to group sample types. There was no uniformly consistent grouping of sample types, but some sample types were more likely to be clustered together than others. In most groupings, either all three soil samples were in a cluster or two of the soil samples, the foundation and boundary samples, were in a cluster. Typically entryway dust samples and floor dust samples were in the same cluster, sometimes with other sample types as well. Air ducts and bedcovers/rugs/upholstery were the sample types most likely to stand apart from other groups of sample types when grouping approaches were carried out.

There were no definitive identifications of sample types with sources of lead. For example, window channels were observed to contain high concentrations of lead in dust. Some of the analyses in the report indicated that there were high levels of barium and zinc, as well as lead, in the window channel samples. Since barium, zinc, and lead were used in paint, this might indicate paint was the source of the lead. However, aluminum and titanium were also present at high levels in window channel samples, and in this study, these elements appeared to be identified with soil. This would indicate a soil source for the lead. Moreover, titanium was also used in paint. Overall, the analyses in this report did not result in a definitive answer to the source of the lead in the window channels.

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COMPREHENSIVE ABATEMENT PERFORMANCE PILOT STUDY: MULTI-ELEMENT DATA ANALYSES

1.0 INTRODUCTION

This report presents the results of a multi-element analysis of data obtained during a pilot study that preceded the Comprehensive Abatement Performance (CAP) Study. This represents Volume II of the CAP Pilot report. Volume I dealt exclusively with the statistical analysis of observed levels of lead (US EPA, 1995). The goal of the CAP Study was to assess the long-term efficacy of lead-based paint abatement. The pilot study was conducted to test the sampling and analysis protocols that were intended for the full study. These protocols called for determining the levels of lead in dust and soil samples collected at residential units. The intention of this report is to summarize the results of an investigation of methods for examining multi-element data and characterizing the multi-element relationships between different sample types in the residences sampled.

1.1 STUDY DESIGN

In the CAP Pilot study, six houses of differing abatement histories were sampled. These houses were located in Denver, Colorado. Two houses were unabated (previously identified as relatively free of lead-based paint) (US EPA, 1995). The remaining four houses were abated using removal methods and/or encapsulation or enclosure methods. One house was abated using primarily removal methods on the interior and primarily encapsulation or enclosure methods on the exterior. Another house was abated using predominantly encapsulation or enclosure methods on the interior and predominantly removal methods on the exterior. The other two houses were abated by primarily the same method on the interior as the exterior (one removal, the other encapsulation or enclosure). For easy reference, Table 1 displays the abatement and renovation history of each of the six houses sampled. (Renovation is described later.)

In the six houses, most of the lead levels in paint were less than 1.0 mg/cm^2. This might make it more difficult to develop hypotheses about sources of lead simply based on the levels of lead observed in different sample types. However, the impetus behind the multi-element analysis approach was the conception that patterns among different elements might reveal themselves in different, nearby sample types.

Table 1. Abatement and Renovation History by House

House	Interior Abatement History	Exterior Abatement History	Renovation
17	Abated: Removal[a]	Abated: E/E[b]	None
19	Unabated	Unabated	Partial
33	Unabated	Unabated	None
43	Abated: Removal	Abated: Removal	None
51	Abated: E/E	Abated: Removal	Full
80	Abated: E/E	Abated: E/E	None

[a] Abated by removal methods.
[b] Abated by encapsulation/enclosure methods.

Along with the determinations of lead obtained in the study, levels of ten other metals were measured within dust and soil samples taken at these houses: aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc. Five of these metals (barium, cadmium, chromium, titanium, and zinc) have been used in the composition of paint. The other five elements are likely to be found in soil (Tisdale, Nelson, and Beaton, 1985). For example, magnesium is found in clay, which is often part of soil samples. The purpose of measuring the levels of these other metals in the samples was to identify groups of sample types that appear to have come from similar sources, with the ultimate goal of identifying prominent sources of lead found in residences.

The major objectives addressed in the analysis of the multi-element data from the pilot study were the following:

(1) Characterize the concentration levels of lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc in samples of household dust and soil;

(2) Determine the effect of renovation and abatement on the concentration of these elements in household dust and soil; and

(3) Investigate the relationships among these elements by sample type (i.e., samples taken from different locations).

The intention of this examination was to identify analysis methods for evaluating multi-element data and to apply these methods to pilot study data to identify any relationships. With data available for only six housing units, few relationships were strongly detectable.

Subsection 1.2 describes the data and gives a summary of the outlier analysis. Section 2 describes the analyses performed and the results. Section 3 is a summary of the key points of the peer review of this report. Section 4 lists references. Appendix A contains tabulations of the data used in the analyses in the report. Appendix B contains technical analyses related to the distribution of the data, the reliability of the measurements, and the identification of outliers.

1.2 DATA

The study design intended the collection of 25 vacuum dust samples and eight core soil samples from each of the six houses in the study, for a total of 150 dust samples and 48 soil samples. The vacuum dust samples were collected from six different locations (window channels[1], window stools[2], air ducts, floors, bedcovers/rugs/upholstery, and entryways). Core soil samples were composite samples of three subsamples. They were taken from just outside the front and back entryways, at different locations on the foundation, and at different locations on the property boundary. The number of dust samples actually collected from each house varied from 16 to 22 for a total of 109 vacuum dust samples. Eight soil samples were collected from each house for a total of 48 soil samples.

Table 2 contains a description of the acronyms used throughout this report in the tables and figures to denote the components from which samples were collected (referred to hereafter as "sample types").

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[1] Window channel: The surface below the window sash and inside the screen and/or storm window. Also called the window trough or the window well.

[2] Window stool: The horizontal board inside the window that extends into the house interior—often called the window sill.

Table 2. Abbreviations for Sample Types Used in Tables and Figures

Media	Acronym	Component/Sample Type
Vacuum Dust Samples	ARD BRU EWY (-I) FLR WCH WST	Air duct Bedcover/rug/upholstery Entryway (-Inside) Floor Window Channel Window Stool
Soil Samples	BDY EWY (-O) FDN	Boundary Entryway (-Outside) Foundation

The dust and soil samples collected during the pilot study were analyzed to determine the amounts of eleven different elements. Listings of the raw element concentration data are displayed in Tables A-1a through A-1f of Appendix A. Each table displays concentrations from a given house for each of the eleven elements by sample medium, sample type, location, and sample ID. House number and sample ID uniquely identify each sample. Only element concentrations (μg/g) were analyzed for this report. Element loadings (μg/ft^2) were also measured for dust samples. However, element loadings are influenced by dust amount, while concentrations are not. Element loading relationships might be masked by differences in household cleaning habits. Therefore, loadings were not considered in this analysis.

The samples were prepared using a modified version of EPA SW846 Method 3050. The modifications were to reagent volumes and final dilution volume. Samples were analyzed by inductively coupled plasma-atomic emission spectrometry using EPA ITD Method 1620. The lower reporting limit for all the data was the instrument detection limit. For each batch analysis an instrument detection limit was calculated. Instrument detection limits were based upon three times the standard deviation of five determinations of a laboratory fortified blank. The upper reporting limit was based upon the highest calibration standard used to calibrate the laboratory instrument.

Twenty-three samples had zinc concentrations above the calibration range of the measuring instrument. One sample had a cadmium concentration above the calibration range. For the 23 samples with elevated zinc concentrations, the maximum detectable concentration was used, after correcting for its dilution factor[3]. These adjusted values were used in the statistical analysis and are identified by superscripts in the appendix tables. Because only one sample had a cadmium concentration above the calibration range, it was excluded from the statistical analysis, rather than adjusted by its dilution factor.

Table 3 summarizes the numbers of dust (vacuum) and soil samples planned and collected, the numbers of extra samples collected, the numbers of analytical results reported, and the numbers of samples included in this multi-element data analysis. Results for seven of the 109 dust samples collected were excluded from the statistical analyses. No soil samples were excluded. One of the seven dust samples omitted was the sample with the elevated cadmium concentration described in the previous paragraph (sample 7 in house 17, see Appendix A-1 for a data listing by house and sample number). Another sample (sample 12 in house 19) was dropped in the laboratory. Four samples (samples 3, 9, and 17 in house 19 and sample 19 in house 43) were eliminated because only lead concentrations were available due to calcium interference. Finally, sample 12 in house 51 was excluded due to sampling problems; the cartridge filled with sawdust prior to completion of the sample collection.

Univariate and multivariate outlier detection tests were applied to the multi-element concentration data. These two tests were applied to natural logarithms of the concentrations of the eleven elements. The univariate test is mainly aimed at identifying individual samples with element concentration outside the range of what is typical. The multivariate test does this also, but in addition, the multivariate test seeks to identify unusual combinations of different elements. Lists of potential outliers were sent back to the laboratory for verification. The results for all but one of the potential outliers were confirmed and included in the analysis as originally reported. The sample for which an error was reported was updated and the corrected value was used in the analysis. This sample is documented in the footnotes to Table A-1b. Details regarding the statistical approach to the outlier analyses and their respective results are provided in Appendix B.

[3] The maximum detectable concentration was 5 µg/mL. The reported concentration depended on the actual amount of dilution prior to chemical analysis.

Table 3. Summary of Planned Samples, Collected Samples, and Analytical Results Used in Multi-Element Analysis

Medium	Type of Sample	Planned Samples to be Collected	Planned Samples Collected	Extra Samples Collected	Analytical Results Reported	Analytical Results Used in Data Analysis
Vacuum Dust	Regular	108	77	1	73[(a),(b)]	71[(c),(d)]
	Vacuum-Wipe Comparison	36	25	0	25	25
	Side-by-side (QC)	6	5	1	6	6
	Total Dust	150	107	2	104	102
Soil	Regular	36	36	0	36	36
	Side-by-side (QC)	6	6	0	6	6
	Side-by-side (interlab comparison)[e]	6	6	0	6	6
	Total Soil	48	48	0	48	48

(a) Sample 19-12 (house 19, sample 12) dropped in lab. No analytical results reported.
(b) ICP analysis hampered by calcium interference for samples 19-03, 19-09, 19-17, and 43-19; no multi-element data reported.
(c) Cadmium concentration was above the upper calibration limit for sample 17-07; excluded from the multi-element analysis.
(d) Cartridge for sample 51-12 filled with sawdust prior to completion of sample collection; sample excluded from lead and multi-element data analyses.
(e) These samples were split for analysis by two labs. The result obtained from the primary lab was included in the multi-element analysis.

2.0 ANALYSIS

The analysis is divided into three parts corresponding to the three major objectives introduced above. Section 2.1 contains a characterization of the concentration levels of the different elements in the various sample types. Section 2.2 describes the estimated effects of abatement and renovation, and Section 2.3 examines the relationships among the elements and sample types.

2.1 COMPARISON OF ELEMENT CONCENTRATIONS FOR HOUSES AND SAMPLE TYPES

A lognormal distribution was identified as a reasonable model for characterizing the concentrations of all of the elements. An analysis leading to this decision is provided in Appendix B. Thus, commonly used descriptive statistics, such as “mean and standard deviation” are replaced by the analogous terms "geometric mean and the log standard deviation" throughout this document. Also provided in appendix B is a quantification of the measurement error associated with characterizing concentrations of each of the eleven elements included.

Due to the general absence of room-level effects found in the analysis of the CAP pilot lead data, the basic experimental unit considered in the multi-element data analysis is the house. House geometric mean concentrations of the eleven elements were the basic quantities used in the statistical analyses. These are tabulated in Table A-2 of Appendix A by sample type and house for each of the eleven elements.

Levels of each of the eleven elements observed varied by sample type. Grand geometric mean concentrations for each element are displayed in Table 4 by sample type. These were obtained by taking the geometric mean of the house geometric means (displayed in Table A-2) for each sample type and element. Thus, each house where a sample was taken (for a particular sample type) is given equal weight in these averages. Each mean is followed by its log standard deviation. This represents a measure of the between-house variation for that response without controlling for abatement or renovation history (which are discussed in the next section).

Notice from Table 4 that three of the four sample types with the lowest lead concentrations were soil samples. The sample types with the highest lead concentration were the two window components and the air ducts, and these lead concentrations were at least twice as high as those in the remaining sample types. Aluminum concentrations in soil sample types were three of the four highest among the nine sample types. Dust samples in window channels had at least twice the barium concentration as the remaining sample types. For cadmium, calcium, magnesium, nickel and zinc, concentrations in soil samples were all lower than those in dust samples. In particular, calcium and magnesium concentrations in dust are more than twice as high as those in soil samples. One can also observe that chromium concentrations were all lower in three soil sample types than in dust samples except in window channel dust sample type. Except for magnesium and potassium, all element concentrations in boundary soil samples were lower than those in the foundation or entryway soil samples.

To quantify the degree of variation in the concentrations of each element across sample types, an analysis of variance was performed on the geometric means for each house. The results of this ANOVA are summarized in Table 5. For all elements except potassium and chromium, the differences across sample types were statistically significant at the level of 0.01.

Table 4. Geometric Mean Concentration and Log Standard Deviation Across Houses by Sample Type

Sample Medium	Sample Type	No. of Units Sampled	Dust Loading (mg/ft²)	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
				Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.
Dust	WCH	4	738	2128	0.97	12940	0.39	1647	1.58	19.1	0.61	33730	0.23	40.1	0.46
	WST	6	46.8	658	1.20	6266	0.36	703	1.16	23.9	1.03	53230	0.51	54.3	0.54
	ARD	5	352	771	0.31	7136	0.32	325	0.60	26.3	1.32	40465	0.61	77.3	0.64
	FLR	6	58.3	260	0.81	6331	0.30	295	0.52	9.3	0.68	25042	0.44	48.7	0.80
	BRU	5	41.6	152	0.72	6248	0.47	254	0.45	9.7	0.62	24598	0.51	55.0	0.52
	EWY-I	6	71.8	314	0.91	10761	0.37	294	0.78	9.5	0.49	32709	1.03	45.4	0.79
Soil	EWY-O	6	.	208	0.90	16058	0.33	276	0.21	5.6	0.85	9814	0.40	40.8	0.67
	FDN	6	.	209	0.87	14491	0.40	257	0.31	4.0	0.41	9812	0.31	28.7	0.28
	BDY	6	.	126	0.79	11373	0.42	166	0.31	2.8	0.51	8576	0.20	23.6	0.31

Sample Medium	Sample Type	No. of Units Sampled	Dust Loading (mg/ft²)	Magnesium		Nickel		Potassium		Titanium		Zinc	
				Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.
Dust	WCH	4	738	5553	0.32	24.0	0.35	2651	0.444	496	0.27	3226	1.07
	WST	6	46.8	4807	0.29	38.0	0.37	2818	0.67	376	0.13	1939	0.66
	ARD	5	352	3877	0.42	40.7	1.17	4260	0.36	262	0.38	4458	0.98
	FLR	6	58.3	3222	0.25	27.8	0.60	4311	0.70	199	0.29	770	0.39
	BRU	5	41.6	3094	0.29	45.0	1.02	4046	0.89	191	0.57	656	0.70
	EWY -I	6	71.8	4419	0.40	20.7	0.36	4045	0.67	351	0.33	722	0.49
Soil	EWY -O	6	.	574	0.16	13.9	0.74	4069	0.26	482	0.23	296	0.37
	FDN	6	.	1054	0.66	11.4	0.27	3476	0.32	421	0.24	372	0.35
	BDY	6	.	636	0.39	9.7	0.30	3504	0.33	372	0.26	178	0.46

Table 5. Results of Analysis of Variance to Test for Significant Differences Among Sample Types, by Element

Element	Root Mean Squared Error	F value	P value	Comment
Pb	1.14	4.47	0.0006	WCH, WST, and ARD had highest concentrations; three soil sample type were among the four lowest
Al	0.48	6.55	0.0001	
Ba	0.95	3.83	0.0019	WCH and WST concentrations were more than twice as high as the remaining sample types.
Cd	1.01	5.54	0.0001	
Ca	0.67	9.71	0.0001	Soil all lower than dust
Cr	0.78	1.59	0.1570	Insignificant differences
Mg	0.48	31.27	0.0001	Soil all lower than dust, EWY lower than FDN
Ni	0.77	4.83	0.0003	Soil all lower than dust
K	0.74	0.55	0.8096	Insignificant differences
Ti	0.38	8.44	0.0001	
Zn	0.76	16.40	0.0001	ARD, WCH, WST higher than the rest

In interpreting differences in average concentrations across sample types, the reader should remember that the houses have different abatement and renovation histories. These effects are discussed later in the report. For example, calcium levels were significantly higher in the renovated houses than in unrenovated houses for four sample types. Such effects impact the average concentration across houses, and are not adjusted for in Figures 1a through 1k.

Figures 1a through 1k display geometric mean sample concentrations by house and building component for lead, barium, zinc, aluminum, titanium, cadmium, calcium, chromium, magnesium, nickel, and potassium. These figures display all the data considered in the analysis. Mean sample concentrations for each house are plotted with different symbols. The grand geometric mean concentrations over all houses are plotted with a circle and connected by a solid line across sample types. **The sample types are arranged according to increasing lead concentration for all elements**. The element concentrations summarized in Table 4 can be seen in these figures. Therefore, the comparisons of grand geometric mean concentrations for all

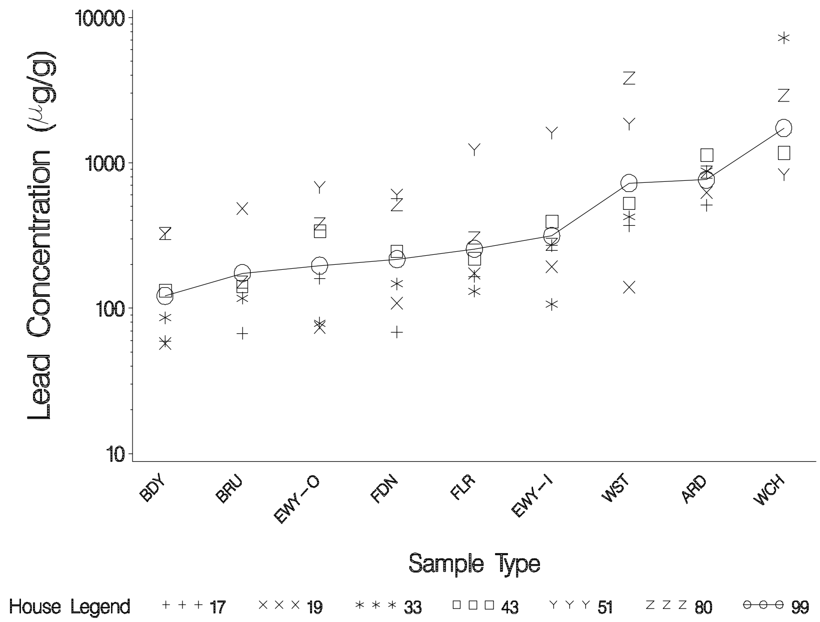


Figure 1a. Lead Concentration vs. Sample Type (Geometric House Mean)

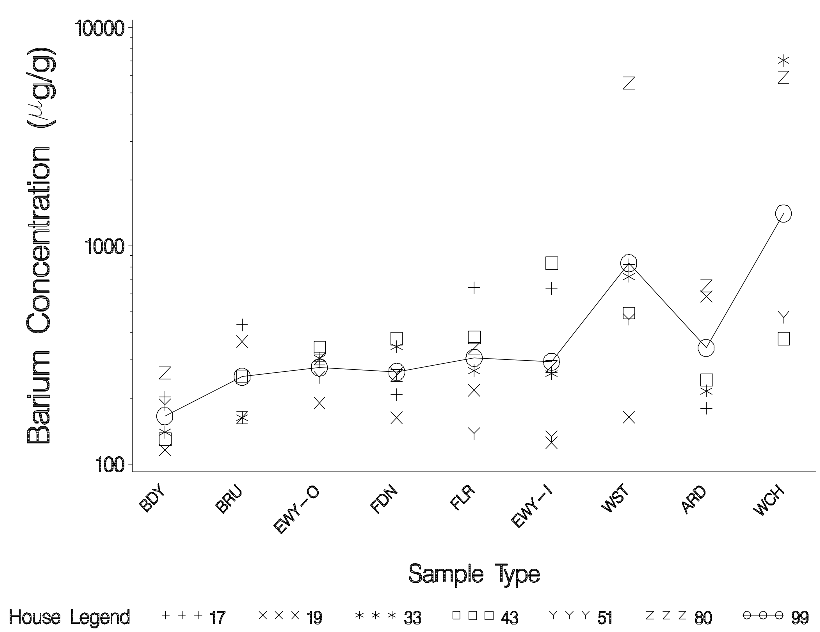


Figure 1b. Barium Concentration vs. Sample Type (Geometric House Mean)

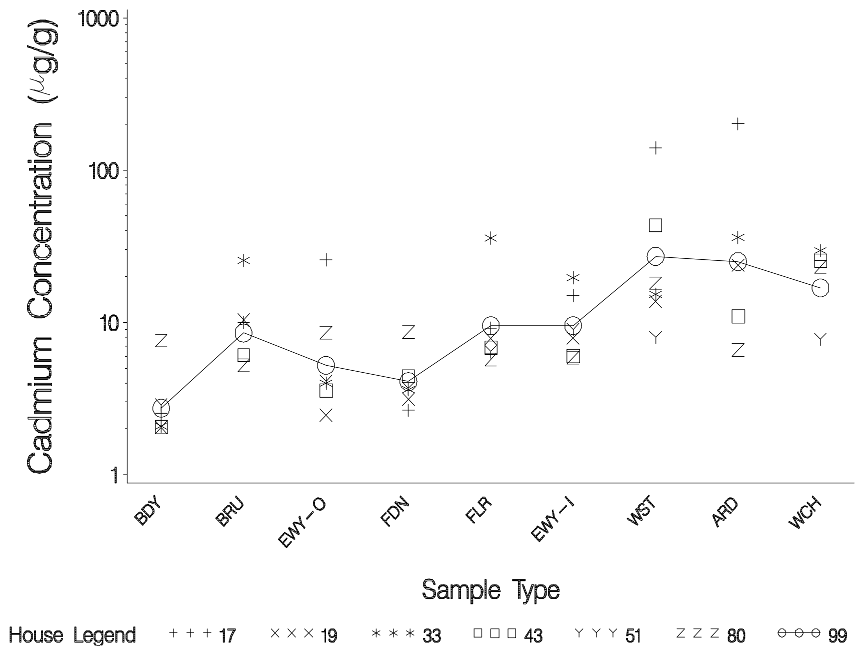


Figure 1c. Cadmium Concentration vs. Sample Type (Geometric House Mean)

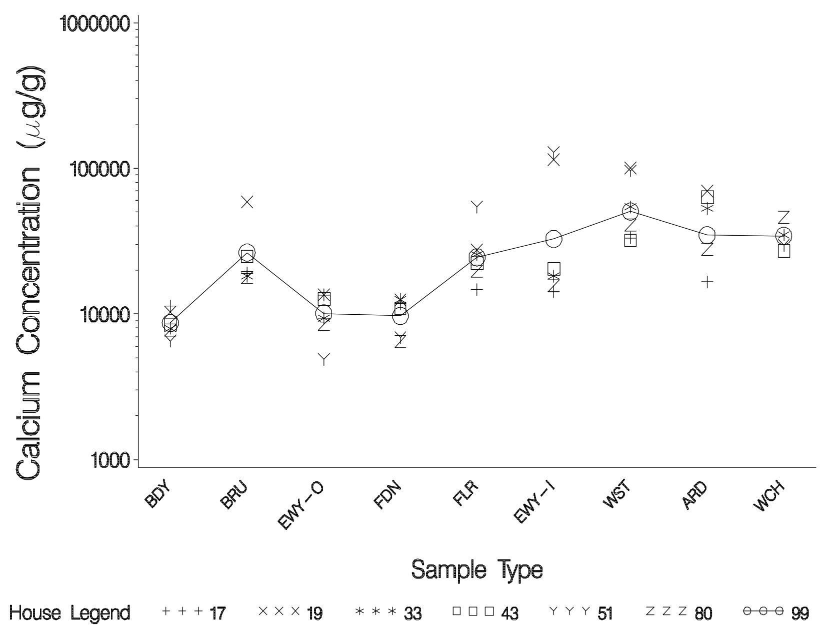


Figure 1d. Calcium Concentration vs. Sample Type (Geometric House Mean)

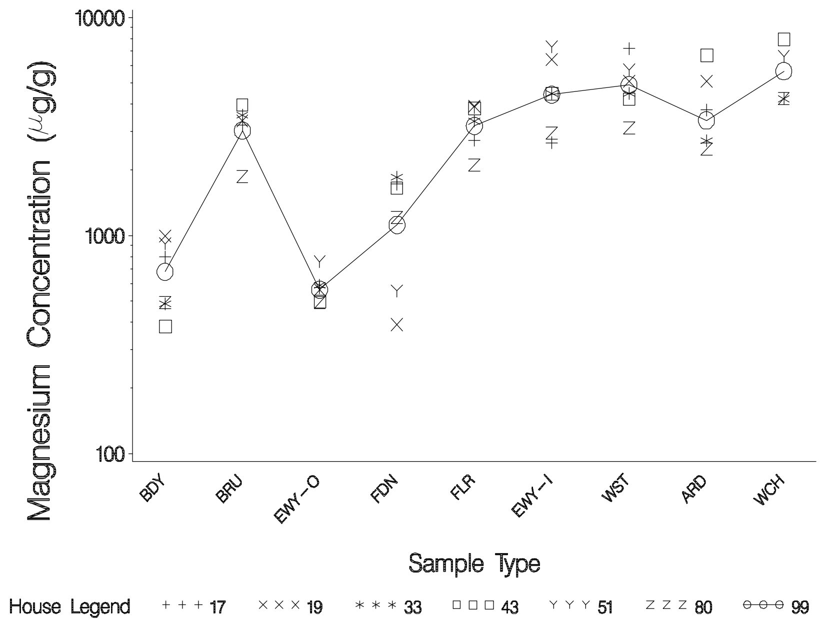


Figure 1e. Magnesium Concentration vs. Sample Type (Geometric House Mean)

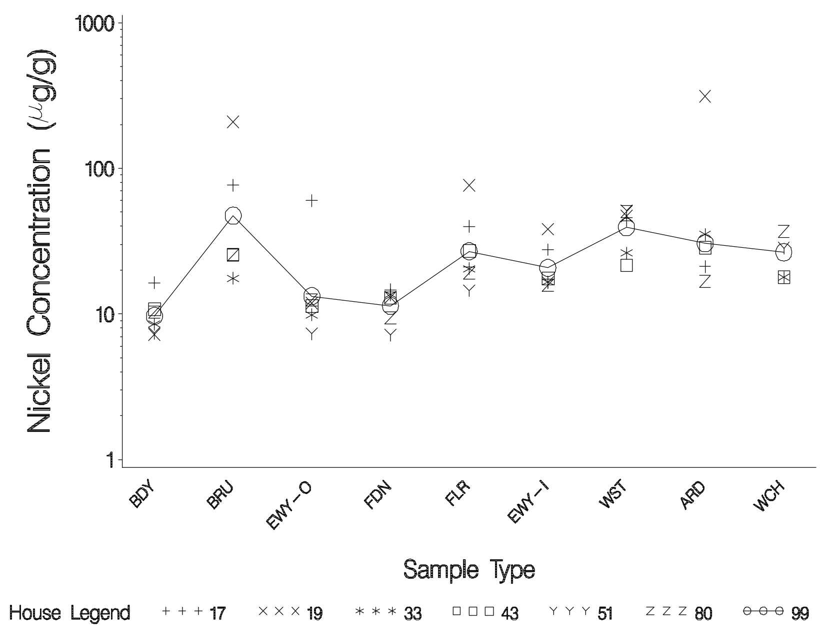


Figure 1f. Nickel Concentration vs. Sample Type (Geometric House Mean)

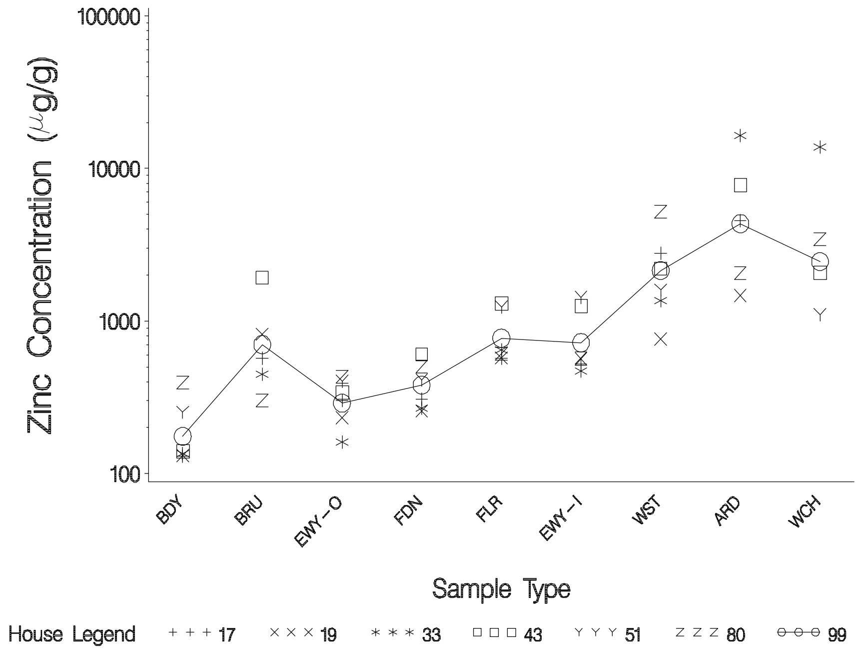


Figure 1g. Zinc Concentration vs. Sample Type (Geometric House Mean)

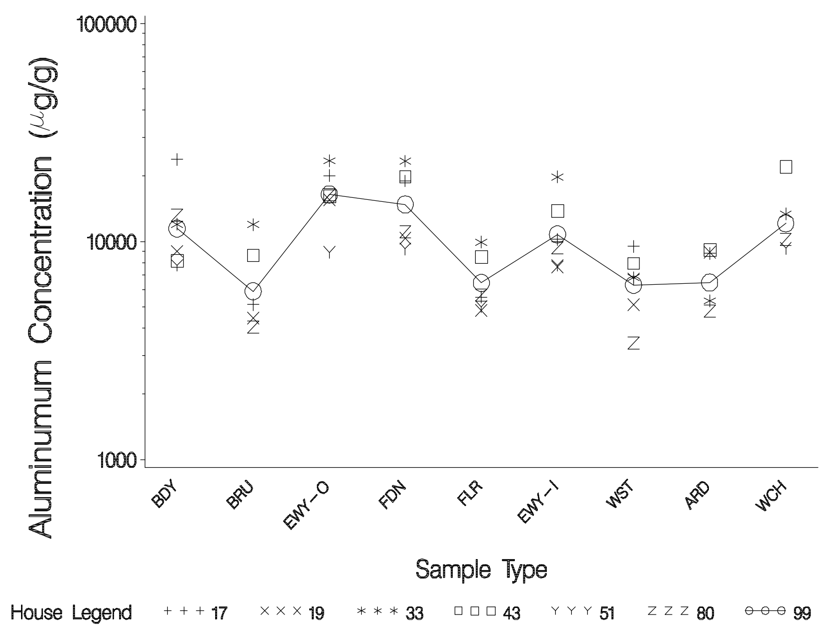


Figure 1h. Aluminum Concentration vs. Sample Type (Geometric House Mean)

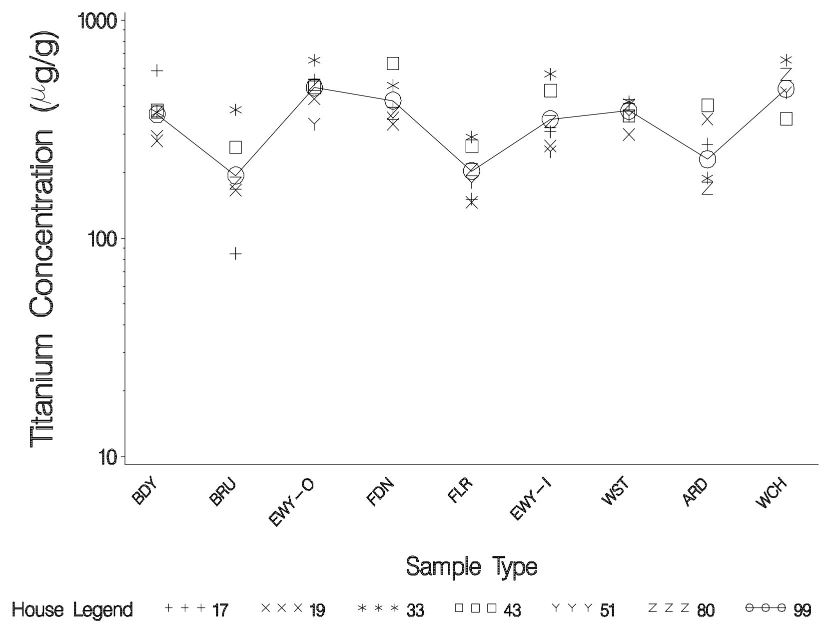


Figure 1i. Titanium Concentration vs. Sample Type (Geometric House Mean)

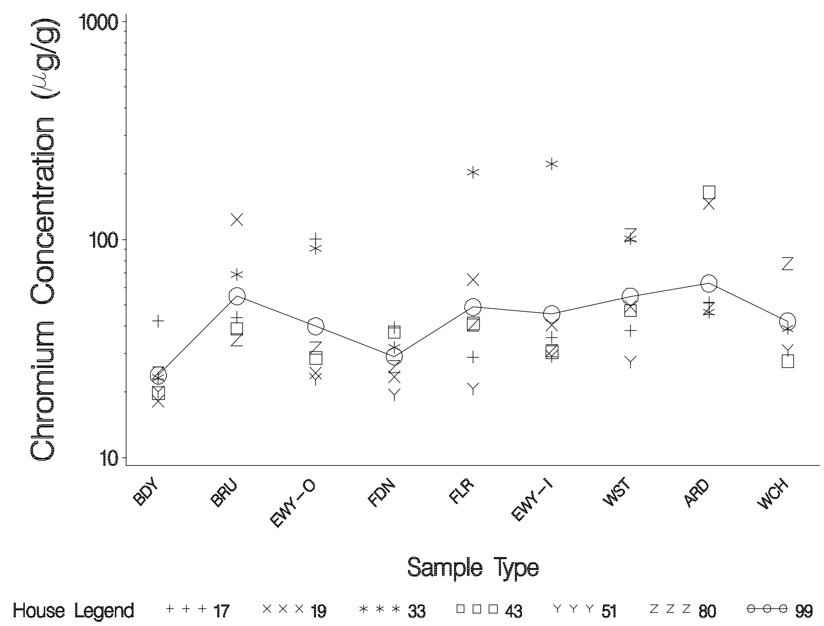


Figure 1j. Chromium Concentration vs. Sample Type (Geometric House Mean)

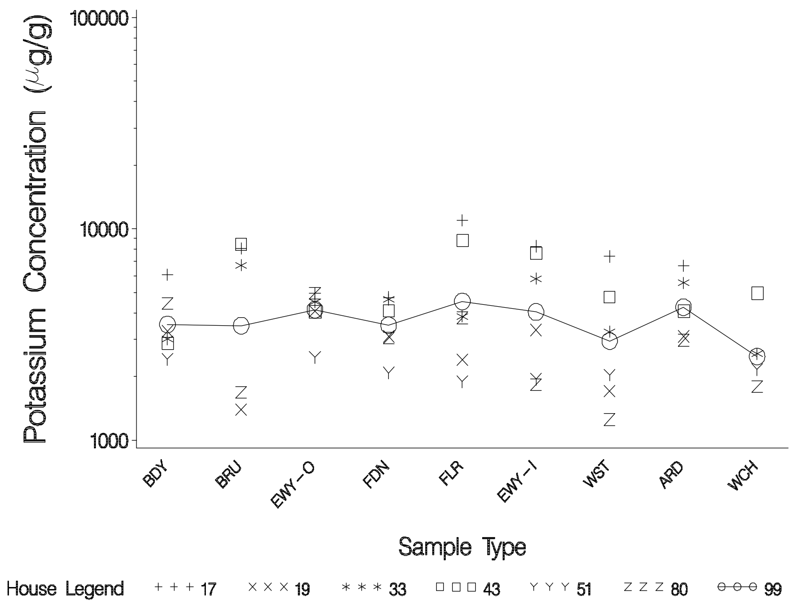


Figure 1k. Potassium Concentration vs. Sample Type (Geometric House Mean)

sample types discussed above can be observed from these figures. Furthermore, these figures as well as the information in Tables 4 and 5 provide a tool for grouping elements based on the pattern similarity.

Figures 1a through 1k are grouped according to similar profiles of element concentrations across sample types. Three groups of elements were identified. The first group, consisting of lead, barium, cadmium, calcium, magnesium, nickel, and zinc, generally had higher concentrations in dust samples than in soil samples. For most of these elements, the highest concentrations were usually found in window channels, window stools, or air ducts. The second group, consisting of aluminum and titanium, generally had higher concentrations in soil than in dust. The third group, consisting of chromium and potassium, had no significant differences in concentration across sample types.

In summary, all elements except chromium and potassium had significant differences in concentration levels across sample types. Three groups of elements were identified: lead, barium, cadmium, calcium, magnesium, nickel, and zinc; aluminum and titanium; and chromium and potassium. Aluminum was the most prominent element in soil, and calcium was the element with the greatest concentrations in dust.

2.2 DIFFERENCES IN MULTI-ELEMENT CONCENTRATIONS RELATED TO ABATEMENT AND RENOVATION HISTORY

The differences in element concentrations associated with abatement and renovation history was assessed by fitting a statistical model containing terms for both renovation and abatement to the data in Appendix A. The model fitted to data for each element was

$$C_j = m + aI_j + rR_j + E_j \qquad j = 1,...,6$$

where

C_j represents the observed average log-concentration in house j,

m represents the average log-concentration in unrenovated unabated houses,

a represents the added effect of abatement,

I_j 1 if house j was abated
0 if house j was an unabated house,

r represents the added effect of a full renovation,

R_j is the degree of renovation house j was undergoing at the time of sampling (see below), and

E_j represents house-to-house variation

House 51 was assigned an R_j value of 1 indicating "full renovation" and House 19 a value of 0.5 indicating "partial renovation". The other four houses were assigned R_j values of zero, indicating that no renovation was being performed. Although only one home received full renovation, with one subject to partial renovation, it is necessary to consider its effect.[4]

In the analysis of the lead data, the method of abatement (E/E or removal) was also considered as a factor in the statistical model. No significant effect was found; and therefore, this effect was not included in the above lead model applied to all elements.

Estimates of the model parameters are reported in Tables 6, 7, and 8. Table 6 contains estimates and log-standard errors of the geometric mean concentration of each element in unrenovated, unabated houses, by sample type. Table 7 contains estimates and standard errors of the ratios of element concentrations in homes having undergone renovation compared element concentrations in unrenovated, unabated homes, by sample type. Table 8 provides analogous estimates of ratios for homes having undergone abatement. In Tables 7 and 8, a ratio of 1.0 implies no estimated difference. An estimate less than 1.0 indicates that lower levels were observed in renovated (abated) houses, while an estimate greater than 1.0 indicates that higher concentrations were observed in renovated (abated) houses. Those ratios that were significantly different from 1.0 at the 5 percent significance level are underlined.

Table 6 shows that air ducts, window stools, and window channels typically had the highest baseline levels (the geometric mean concentrations for unrenovated/unabated houses) of lead, calcium and zinc. Soil samples generally had the lowest concentrations for these elements. The window channel dust samples had especially high baseline concentrations of barium and lead relative to the concentrations of the other elements. In this manner, window channel dust samples seemed to differ from the other types of samples.

[4] Although having only six houses makes it difficult to control for the effects of renovation, ignoring this factor might bias estimates of differences between abated and unabated houses and increase the uncertainty in these estimates. Recall also that this was a pilot study, performed to develop methodology for the subsequent full study involving many more houses.

Close attention should be given to the log standard errors of the estimates in Tables 7 and 8. Most of these are very large in comparison to the logarithm of the multiplicative estimates.

Note that a total of 198 statistical tests was performed in the analysis supporting the results in Tables 7 and 8. Each test was performed at the 5 percent level. Therefore, even if there were no effects of abatement or renovation on any of these element concentrations, it would still be expected that approximately 5 tests would be significant for each table. **Thirteen tests results were found to be significant for renovation effects.** There were two cases (lead on floors and lead in interior entryways) where lead was significantly higher in dust samples in renovated houses as compared to unrenovated houses. **There were a number of cases where elements with typically higher concentrations in dust than in soil had significantly higher concentrations in a renovated house.** This was true for calcium on window stools, floors, beds/rugs/upholstery, and interior entryways, for magnesium in interior entryways, and for nickel in air ducts. Cadmium in window channels was the exception to this trend. **Correspondingly, there were cases of elements which generally had higher concentrations in soil than in dust where the soil concentration was significantly lower in a renovated house.** This was true for aluminum and titanium in exterior entryways. Finally, potassium, which showed no significant differences across sample types in Section 2.1, had significantly lower concentrations in exterior entryways and foundation samples at renovated houses.

For abated houses, there were five cases of significance. **As noted above, there could occur strictly due to chance, even if there were no differences between abated and unabated houses. There were two cases where lead was significantly higher in abated houses: lead in interior entryways and lead in exterior entryways. Zinc was also significantly higher in exterior entryways at abated houses.** Calcium in window stools and chromium in floors were significantly lower.

Table 6. Model Estimates and Log Standard Errors of Geometric Mean Concentrations in Unrenovated Unabated Houses

Sample Medium	Sample Type	# Houses	Lead Geo Mean (µg/g)	Lead Log Std. Err.	Aluminum Geo Mean (µg/g)	Aluminum Log Std. Err.	Barium Geo Mean (µg/g)	Barium Log Std. Err.	Cadmium Geo Mean (µg/g)	Cadmium Log Std. Err.	Calcium Geo Mean (µg/g)	Calcium Log Std. Err.	Chromium Geo Mean (µg/g)	Chromium Log Std. Err.
Dust	WCH	4	7238	0.64	13346	0.54	7058	1.95	29.7	0.07	34866	0.37	39	0.72
	WST	6	226	1.17	5808	0.39	478	1.11	21.4	0.89	57057	0.12	87	0.46
	ARD	5	875	0.41	5341	0.36	216	0.68	36.0	1.84	53114	0.68	46	0.69
	FLR	6	102	0.33	7687	0.30	313	0.31	19.1	0.59	20998	0.25	141	0.36
	BRU	5	117	0.45	11954	0.39	163	0.49	25.4	0.34	18230	0.18	69	0.12
	EWY-I	6	96	0.19	14146	0.34	255	0.47	13.0	0.57	25873	0.35	109	0.63
Soil	EWY-O	6	63	0.43	22668	0.10	261	0.15	3.9	0.81	13126	0.36	60	0.68
	FDN	6	102	0.89	18568	0.33	252	0.37	3.6	0.48	13395	0.27	32	0.18
	BDY	6	53	0.81	11492	0.44	128	0.30	2.1	0.57	9977	0.25	21	0.33

Sample Medium	Sample Type	# Houses	Magnesium Geo Mean (µg/g)	Magnesium Log Std. Err.	Nickel Geo Mean (µg/g)	Nickel Log Std. Err.	Potassium Geo Mean (µg/g)	Potassium Log Std. Err.	Titanium Geo Mean (µg/g)	Titanium Log Std. Err.	Zinc Geo Mean (µg/g)	Zinc Log Std. Err.
Dust	WCH	4	4237	0.45	17.9	0.50	2563	0.72	656	0.33	13783	0.35
	WST	6	4501	0.35	31.3	0.41	2784	0.77	370	0.13	1229	0.37
	ARD	5	2719	0.50	35.2	0.27	5553	0.41	188	0.44	16504	0.67
	FLR	6	3337	0.25	41.2	0.69	4184	0.46	222	0.33	555.2	0.40
	BRU	5	3558	0.39	17.6	0.64	6723	0.92	387	0.57	447.8	0.94
	EWY-I	6	4400	0.23	24.6	0.43	5575	0.70	444	0.28	439.1	0.40
Soil	EWY-O	6	535	0.11	13.3	0.81	4955	0.12	601	0.08	183.1	0.19
	FDN	6	1175	0.43	14.9	0.20	4458	0.19	443	0.26	269.5	0.29
	BDY	6	703	0.45	8.47	0.21	3500	0.33	338	0.22	120.8	0.52

Table 7. Ratio of Element Concentrations in Renovated Homes to Concentrations in Unrenovated Homes, Estimates and Log Standard Errors

Sample Medium	Sample Type	Lead Effect	Lead Log Std. Err.	Aluminum Effect	Aluminum Log Std. Err.	Barium Effect	Barium Log Std. Err.	Cadmium Effect	Cadmium Log Std. Err.	Calcium Effect	Calcium Log Std. Err.	Chromium Effect	Chromium Log Std. Err.
Dust	WCH	0.45	0.62	0.62	0.44	0.31	5.70	0.32	0.01	0.84	0.21	0.67	0.78
	WST	1.34	1.57	0.96	0.24	0.27	1.40	0.21	0.91	2.83	0.02	0.43	0.24
	ARD	0.51	1.32	2.81	1.05	7.37	3.66	0.43	27.17	1.72	3.66	9.89	3.84
	FLR	4.67	0.12	0.66	0.10	0.35	0.11	0.59	0.39	2.55	0.07	0.44	0.15
	BRU	17.08	1.64	0.14	1.20	5.01	1.92	0.17	0.92	10.45	0.26	3.19	0.11
	EWY-I	4.87	0.04	0.57	0.13	0.25	0.25	0.84	0.37	9.80	0.14	0.56	0.45
Soil	EWY-O	2.12	0.21	0.50	0.01	0.72	0.03	0.43	0.75	0.54	0.15	0.38	0.53
	FDN	2.29	0.91	0.49	0.13	0.78	0.16	0.78	0.27	0.77	0.09	0.57	0.04
	BDY	1.87	0.67	0.57	0.22	0.93	0.10	0.86	0.37	0.81	0.06	0.71	0.12

Sample Medium	Sample Type	Magnesium Effect	Magnesium Log Std. Err.	Nickel Effect	Nickel Log Std. Err.	Potassium Effect	Potassium Log Std. Err.	Titanium Effect	Titanium Log Std. Err.	Zinc Effect	Zinc Log Std. Err.
Dust	WCH	1.14	0.30	1.10	0.38	0.72	0.78	1.04	0.16	0.41	0.18
	WST	1.27	0.14	1.59	0.19	0.52	0.67	0.85	0.02	0.47	0.16
	ARD	3.52	1.98	79.23	0.58	0.31	1.34	3.48	1.55	0.01	3.61
	FLR	1.38	0.07	0.84	0.54	0.28	0.25	0.74	0.12	1.45	0.18
	BRU	0.88	1.22	141.04	3.23	0.04	6.74	0.18	2.61	3.35	7.14
	EWY-I	2.21	0.06	1.09	0.21	0.39	0.55	0.58	0.09	1.91	0.18
Soil	EWY-O	1.36	0.01	0.44	0.74	0.56	0.02	0.62	0.01	1.25	0.04
	FDN	0.27	0.21	0.63	0.05	0.52	0.04	0.72	0.08	0.90	0.09
	BDY	1.95	0.14	0.62	0.05	0.63	0.13	0.65	0.05	1.24	0.30

Table 8. Ratio of Element Concentrations in Abated Homes to Concentrations in Unabated Homes, Estimates and Log Standard Errors

Sample Medium	Sample Type	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	0.26	0.62	1.13	0.44	0.21	5.70	0.82	0.01	1.02	0.21	1.19	0.78
	WST	4.45	1.03	1.09	0.16	2.93	0.92	2.11	0.60	<u>0.61</u>	0.01	0.68	0.16
	ARD	0.91	0.22	1.36	0.17	1.42	0.61	0.68	4.53	0.58	0.61	1.60	0.64
	FLR	2.27	0.08	0.87	0.07	1.36	0.07	0.41	0.26	0.92	0.05	<u>0.27</u>	0.10
	BRU	0.96	0.27	0.47	0.20	1.61	0.32	0.27	0.15	1.11	0.04	0.56	0.02
	EWY-I	<u>3.25</u>	0.03	0.82	0.09	2.08	0.16	0.67	0.24	0.60	0.09	0.33	0.30
Soil	EWY-O	<u>4.51</u>	0.14	0.77	0.01	1.22	0.02	2.41	0.49	0.81	0.10	0.81	0.34
	FDN	2.13	0.60	0.90	0.08	1.13	0.10	1.30	0.18	0.69	0.06	1.07	0.02
	BDY	2.42	0.44	1.14	0.14	1.49	0.07	1.58	0.25	0.92	0.04	1.23	0.08

Sample Medium	Sample Type	Magnesium		Nickel		Potassium		Titanium		Zinc	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	1.37	0.30	1.44	0.38	1.17	0.78	0.68	0.16	0.19	0.18
	WST	1.01	0.09	1.12	0.12	1.30	0.44	1.09	0.01	2.63	0.10
	ARD	1.46	0.33	0.62	0.10	0.78	0.22	1.41	0.26	0.25	0.60
	FLR	0.84	0.05	0.59	0.36	1.69	0.16	0.95	0.08	1.42	0.12
	BRU	0.81	0.20	2.10	0.54	0.72	1.12	0.41	0.44	1.55	1.19
	EWY-I	0.75	0.04	0.75	0.14	0.88	0.36	0.86	0.06	1.65	0.12
Soil	EWY-O	0.99	0.01	1.46	0.49	0.92	0.01	0.86	0.00	<u>1.89</u>	0.03
	FDN	1.38	0.14	0.80	0.03	0.88	0.03	1.05	0.05	1.68	0.06
	BDY	0.88	0.09	1.37	0.03	1.17	0.08	1.23	0.03	1.55	0.20

An underline indicates significant effect at the 0.05 level.

Figure 2a displays the estimates in Table 6 (unrenovated, unabated house geometric means), portrayed on a log scale. Elements were sorted by geometric mean concentrations in boundary soil. A distinction between sample types was observed in the shapes depicted in these figures. Therefore, the sample types were presented in three groups. The first column displays the results for window channels, window stools, and air ducts. The second column displays the corresponding results for floors, bedcover/rug/upholstery, and interior entryways. The last column contains the results for the three soil samples: boundary, entryway, and foundation.

The pattern in the concentrations observed across elements appears similar for the three soil sample types: a monotonic increase from left to right. A noticeable, but less consistent pattern, also appears to be present for interior entryway and beds/rugs/ upholstery, and even for floors and window stools. In this pattern, a cluster of four dots appears in the lower left corner of the plot, a cluster of three dots appears in the middle, and there is a cluster of four dots in the upper right part of the plot. Air ducts and window channels stand on their own. Neither air ducts nor window channels appears to be similar to the other sample types or to each other.

Figure 2b illustrates the renovation effects presented in Table 7. Log scale was used because of two very high ratios of concentrations in renovated homes to concentrations in unrenovated homes for nickel in air duct and bedcover/rug/upholstery samples. The log transformed ratios appear to have a similar pattern for the three soil sample types, except the ratio for magnesium in foundation soil samples, which looks out of pattern. Another pattern can be observed in floor and entryway dust samples. For these sample types, magnesium, lead, zinc, barium, and cadmium appear in one cluster; chromium, titanium, potassium, nickel, and aluminum form another cluster; and calcium stands alone. A third pattern shows some similarities between window channels and window stools. Air duct and bed/rug/upholstery dust samples are distinct.

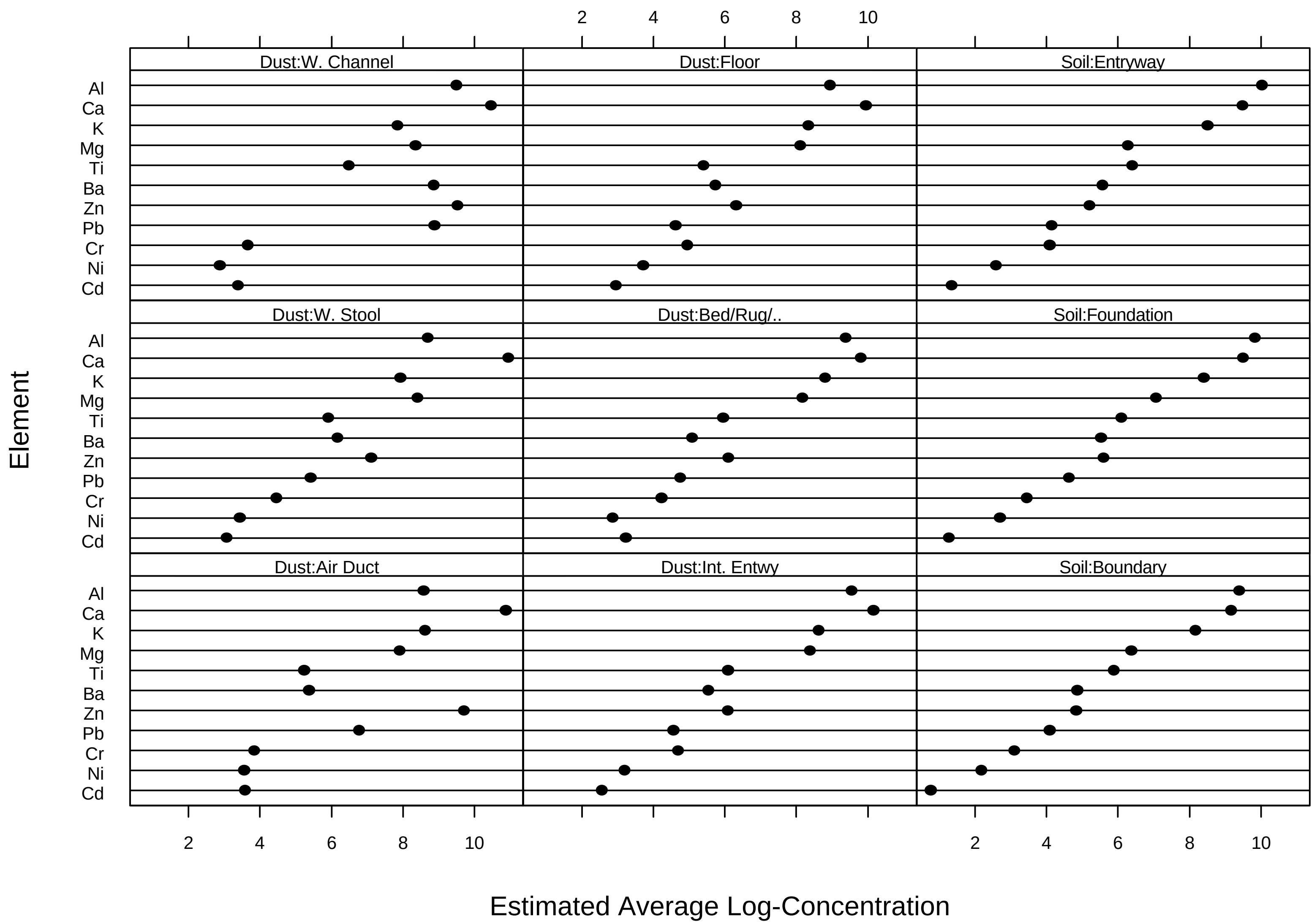


Figure 2a. Estimated Average Log concentrations in Unrenovated, Unabated Units, for Each Element and Each Sample Type. Elements Sorted by Geometric Average Concentration in Boundary Soil

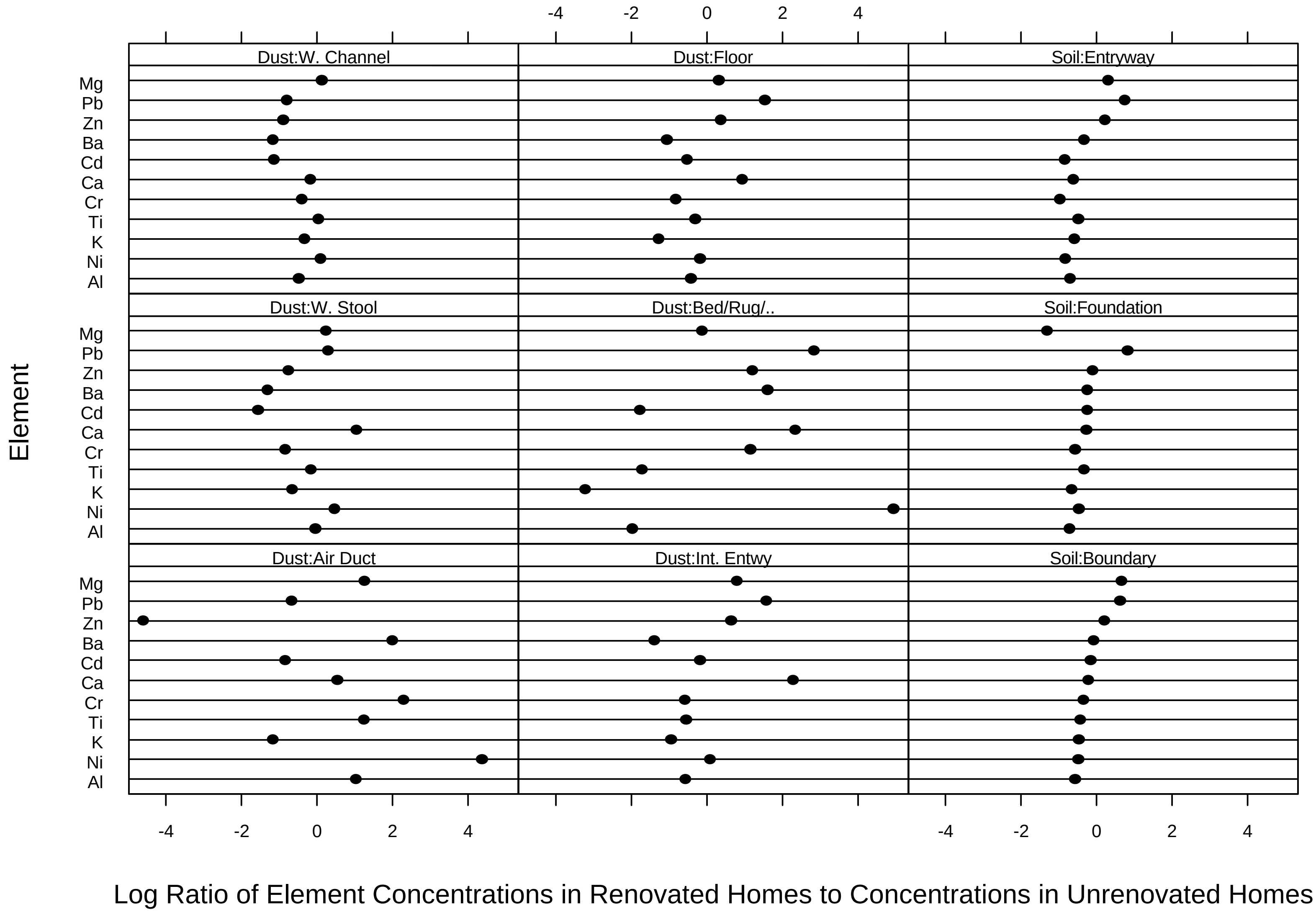


Figure 2b. Log Ratio of Element Concentrations in Renovated Homes to Concentrations in Unrenovated, Unabated Homes, Sorted by Ratios in Boundary Soil

Figure 2c displays the abatement effects estimated in Table 8. There is no clear similarity pattern among the sample types.

2.3 RELATIONSHIPS AMONG SAMPLE TYPES

This section explores the relationships among the sample types by analyzing the multi-element data. There are three subsections. The first subsection discusses pairwise correlations between lead and the other elements. The second subsection includes correlation scatterplots for each sample type, with the correlations between elements being displayed for each sample type. A visual inspection of the correlation scatterplots is used to identify similar sample types. The last subsection covers a principal components analysis of the multi-element data which reduces the dimensionality of the analysis, and suggests graphically which sample types are similar. The analyses in Subsection 2.3.1 and 2.3.2 were done with the (unadjusted) concentration data described in Section 2.1. The analyses in Subsection 2.3.3 were done with the adjusted concentrations described in Section 2.2.

2.3.1 Correlations Between Lead and the Other Elements

Table 9 displays the estimated correlation between average logarithmic transformed concentrations for each house for lead and each of the remaining ten elements by sample type. Lead was most frequently positively correlated with zinc at a statistically significant level (0.05). In particular, the correlation between these elements was significantly positive in boundary soil samples, interior entryway dust samples, exterior entryway soil samples and window stool dust samples. There was also a significantly positive correlation between lead and calcium in dust samples taken from bedcover/rug/upholstery. Correlations between lead and calcium in boundary and foundation soil samples and nickel in foundation soil samples were significantly negative.

To investigate the overall association of lead with all of the other elements, one can generally use a multiple correlation procedure. However, there must be at least as many houses as there are elements of interest. Therefore, this procedure is not applicable for this pilot study data.

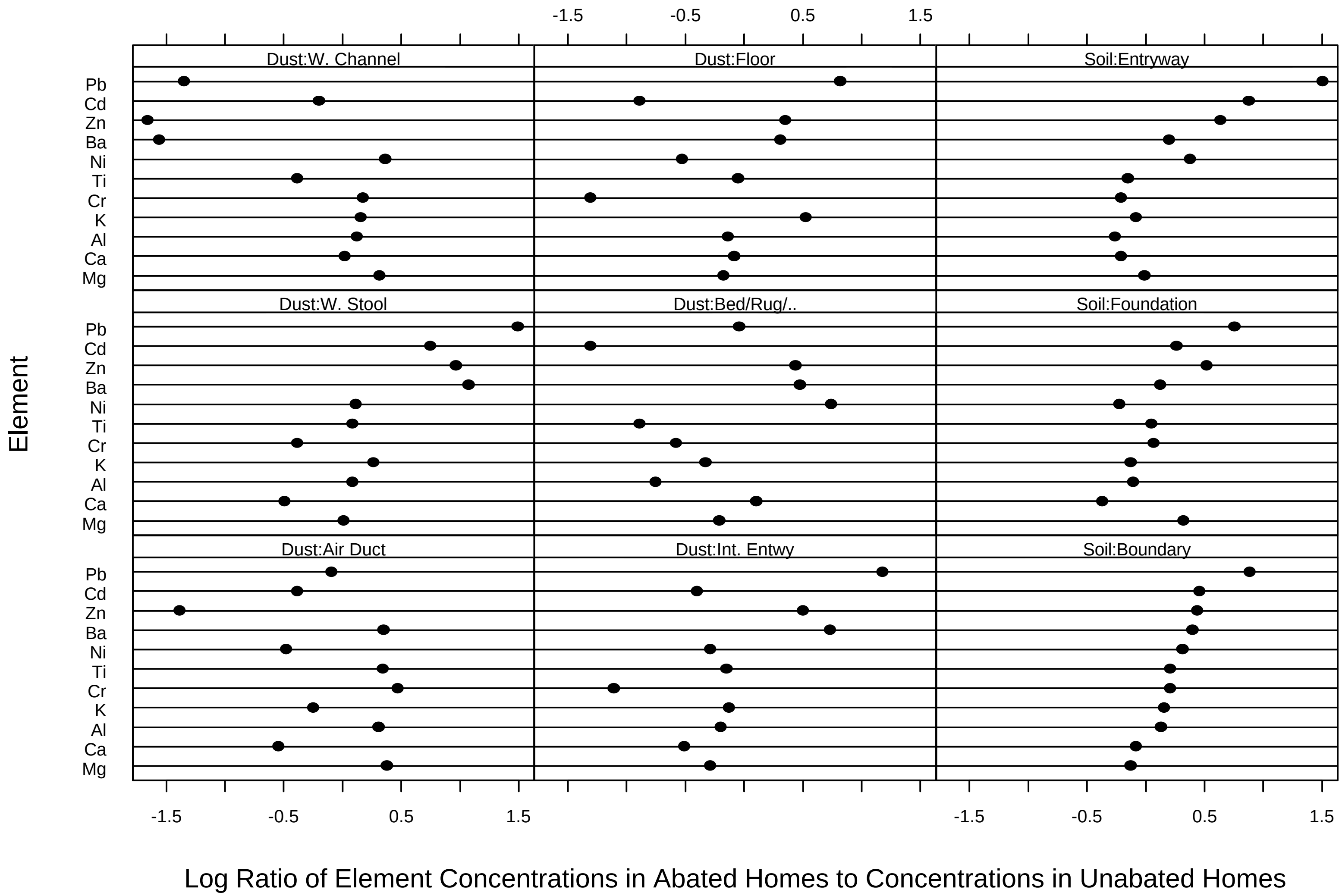


Figure 2c. Log Ratio of Element Concentrations in Abated Homes to Concentrations in Unabated Homes, Sorted by Ratios in Boundary Soil

Table 9. Estimated Correlation Between Lead and Remaining Elements, by Sample Type (Log-transformed concentrations)*

Sample Type	# of Houses	Aluminum	Barium	Cadmium	Calcium	Chromium	Magnesium	Nickel	Potassium	Titanium	Zinc
Air Ducts	5	-0.30	0.04	-0.77	0.55	0.27	0.14	-0.28	-0.31	0.02	0.43
Boundary Soil	6	-0.38	0.60	0.69	-0.86	-0.30	-0.22	-0.26	-0.34	-0.32	0.90
Bedcover/Rug/ Upholstery	5	-0.32	0.07	-0.09	0.89	0.72	0.01	0.55	-0.77	0.18	0.19
Entryway (Inside)	6	-0.56	-0.17	-0.40	0.51	-0.67	0.41	-0.29	-0.44	-0.56	0.86
Entryway (Outside)	6	-0.72	0.34	0.12	-0.65	-0.49	0.22	-0.24	-0.53	-0.60	0.90
Foundation Soil	6	-0.53	0.37	0.72	-0.89	-0.59	-0.20	-0.90	-0.73	-0.06	0.67
Floor Dust	6	-0.47	-0.64	-0.53	0.77	-0.68	0.16	-0.59	-0.54	-0.18	0.62
Window Channel	6	-0.47	0.78	-0.28	-0.15	0.18	-0.49	0.31	-0.43	0.47	0.74
Window Stool	4	-0.04	0.92	0.72	0.57	0.47	-0.85	-0.20	-0.26	0.83	0.98

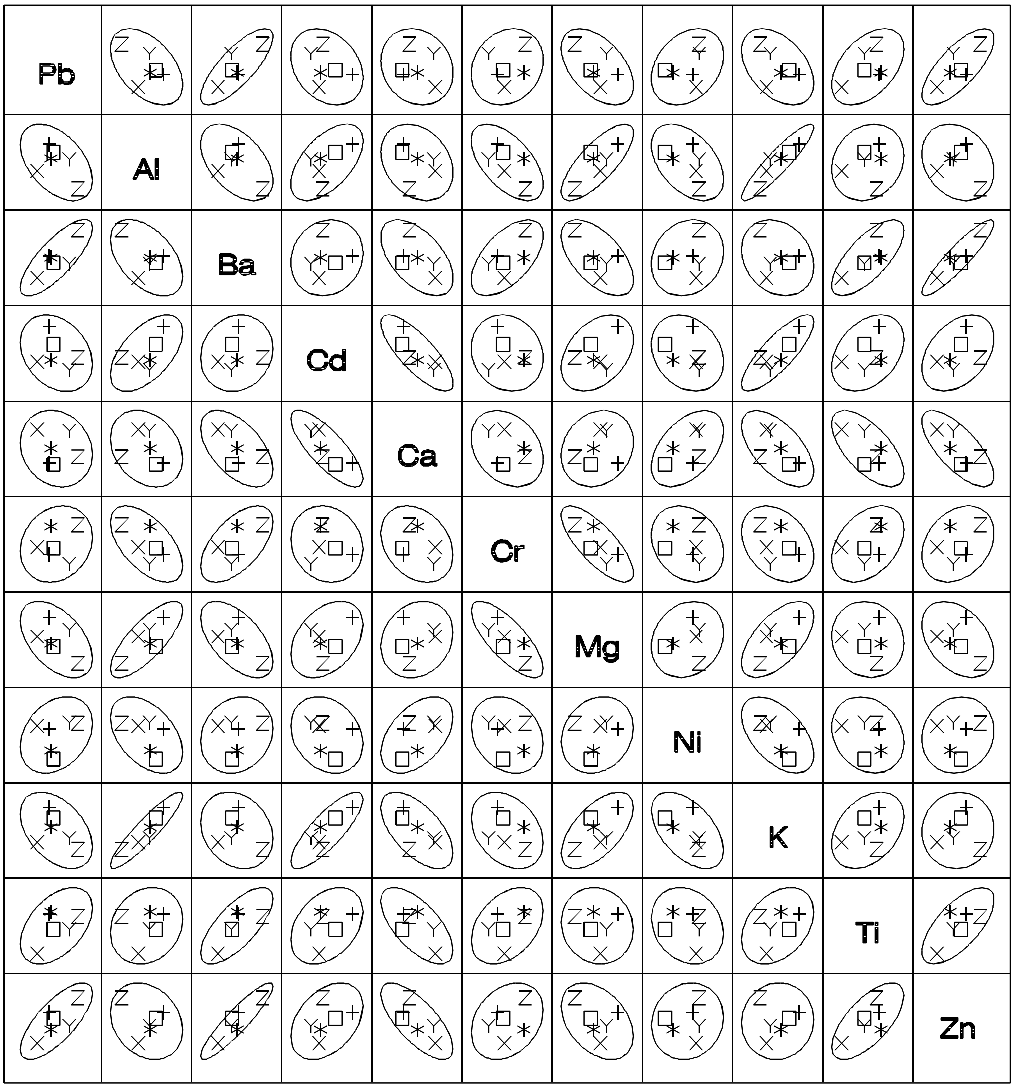
* Underlined correlations were significant at the 0.05 level.

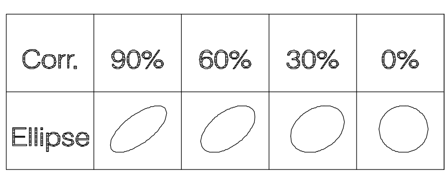
2.3.2 Bivariate Relationships Among the Elements

Displays portraying the bivariate relationships among the eleven elements are provided in Figures 3a through 3i. For each sample type, average log-concentrations for each house are plotted for each pair of elements. Ellipses are drawn on each plot that represent 95% of the estimated bivariate distribution. Those plots for which the ellipse is narrow represent pairs of elements for which there was a strong observed correlation. Pairs of elements which are negatively correlated have an ellipse with the major axis running from upper left to lower right. The magnitude of the correlation can be inferred from the shape of the ellipse by comparing it to the key at the bottom of each graph.

On the plots in Figures 3a through 3i, each house is identified with a different symbol. This permits determining whether certain houses have similar characteristics with respect to the various elements and/or sample types.

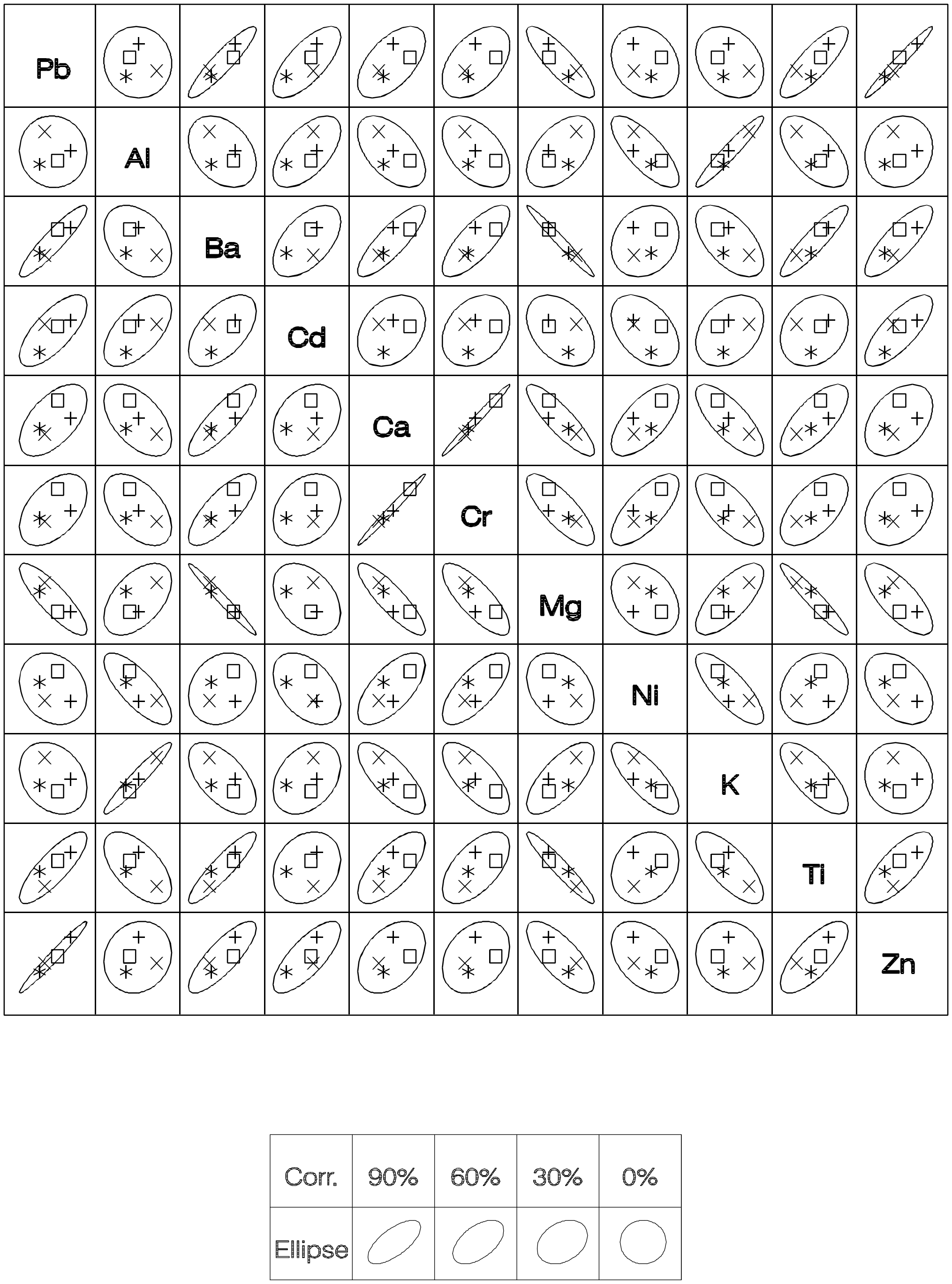
Although it is difficult to interpret the plots in Figures 3a through 3i, some patterns can be seen in these correlation scatterplots. Window channel and window stool samples are characterized by positive correlations among lead, barium, titanium, and zinc. Among the other samples types, it is interesting to note that the foundation sample type nearly had this same pattern in its scatterplot. Foundation and boundary samples were characterized by positive correlations among aluminum, chromium, nickel, potassium, and titanium. Floor samples and interior entryway samples displayed positive pairwise correlations between lead and zinc, aluminum and titanium, barium and potassium, calcium and magnesium, cadmium and chromium, and lead and calcium. These samples also had a negative pairwise correlation between lead and chromium. Exterior entryway samples had some of the characteristics of both the other soil samples and the floor and interior entryway samples. However, the exterior entryway samples generally did not have positive correlations as strong as those of the other soil samples among the five elements aluminum, chromium, nickel, potassium, and titanium. Also, the exterior entryway samples had a negative correlation between calcium and magnesium and a negative correlation between lead and calcium, in contrast to the positive correlations for the floor and interior entryway samples.





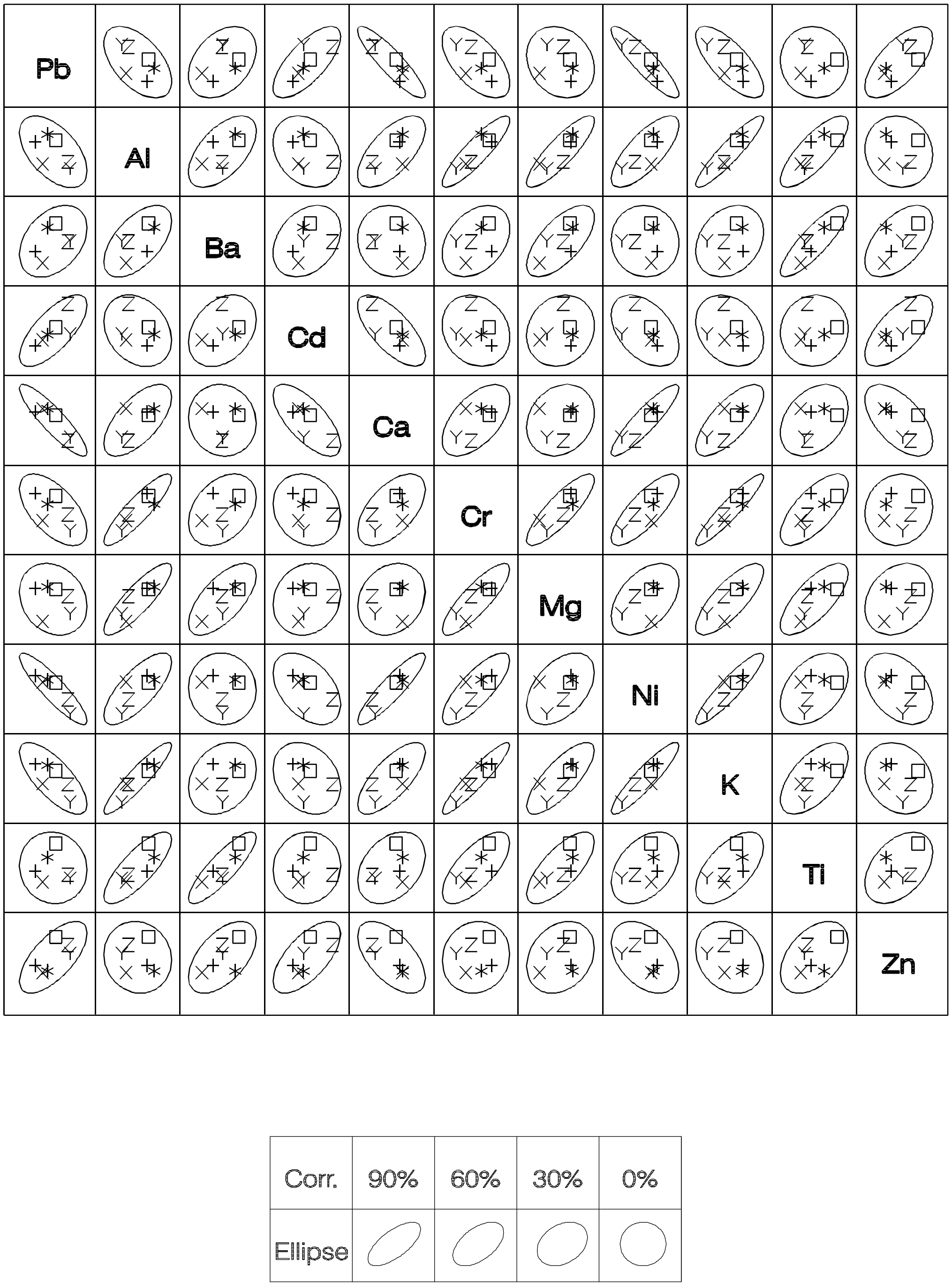
House Legend: *** = 17** Q = **19** + = **33**
X = 43 **Z = 51** **Y = 80**

Figure 3a. Window Channel House Mean Correlation Scatterplot



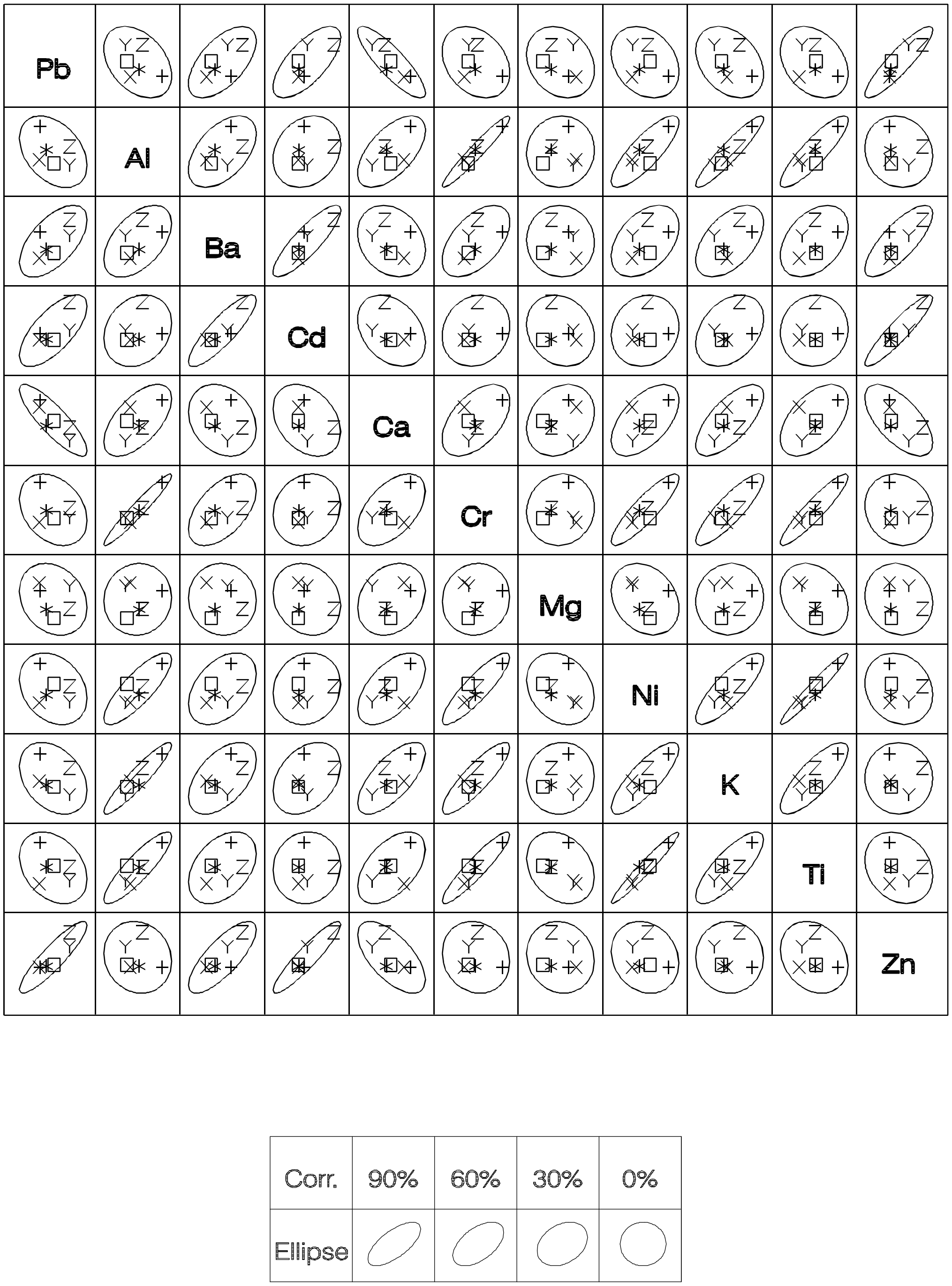
House Legend: * = 17 Q = 19 + = 33
X = 43

Figure 3b. Window Stool House Mean Correlation Scatterplot



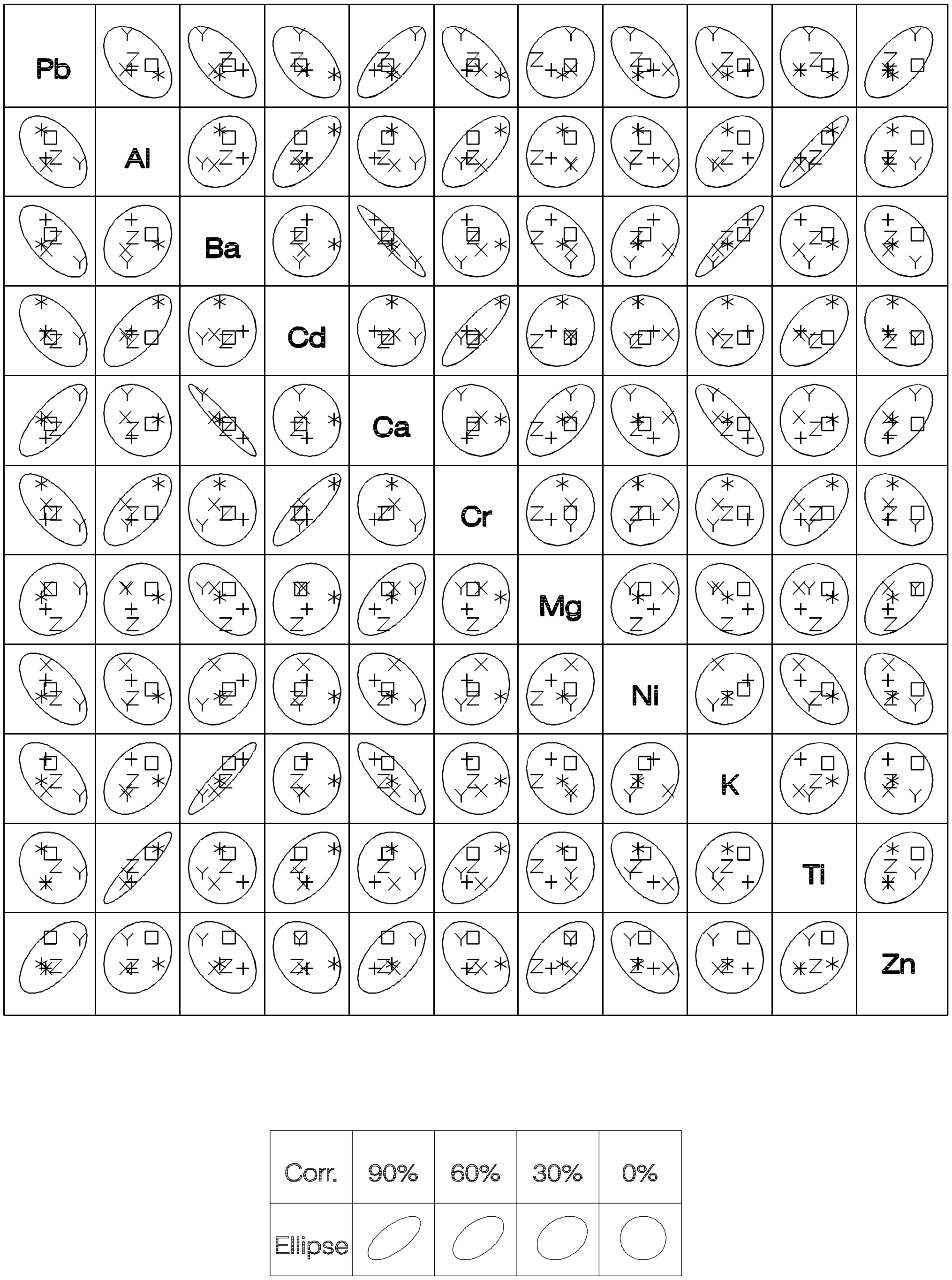
House Legend: *** = 17** Q = **19** + = **33**
X = 43 **Z = 51** **Y = 80**

Figure 3c. Foundation Soil House Mean Correlation Scatterplot



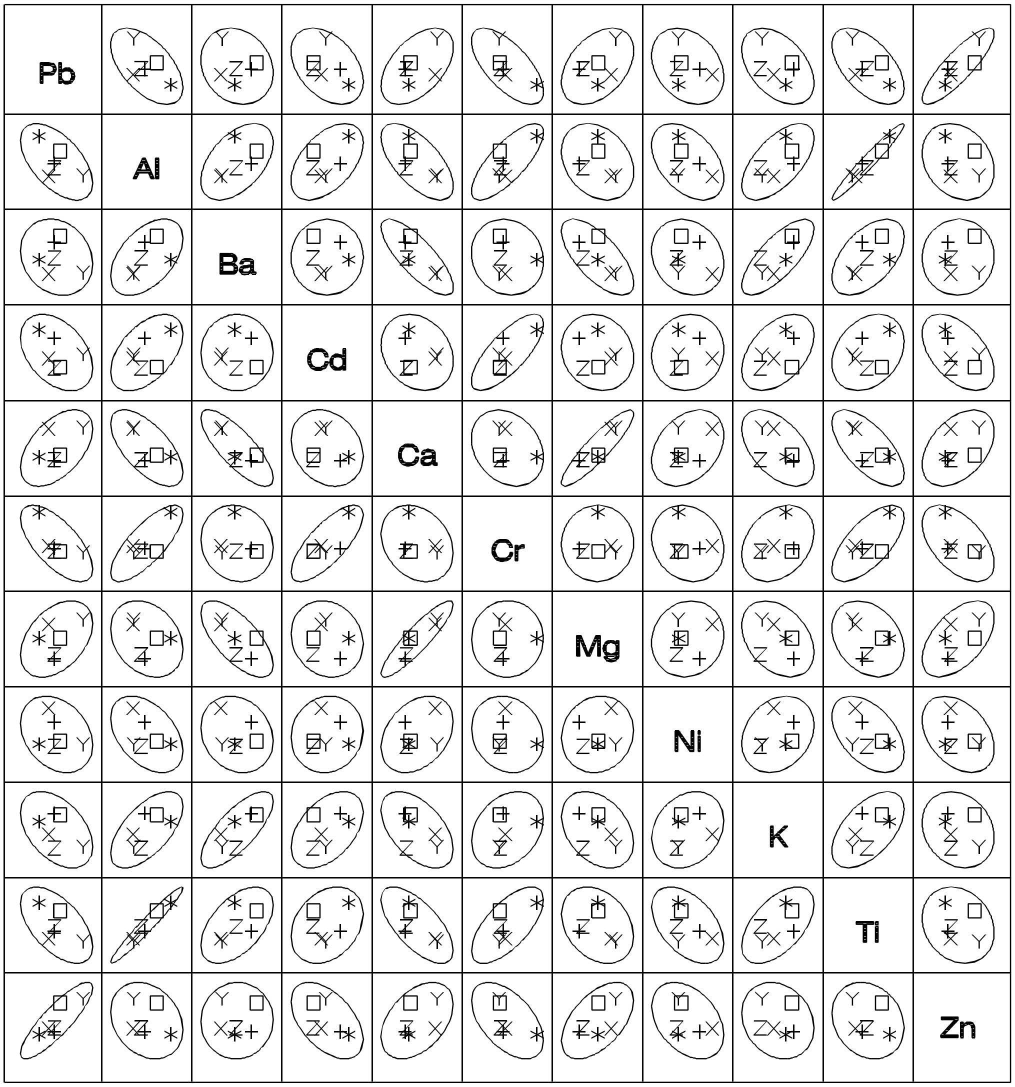
House Legend: * = 17 Q = 19 + = 33
X = 43 Z = 51 Y = 80

Figure 3d. Boundary Soil House Mean Correlation Scatterplot



House Legend: * = 17 Q = 19 + = 33
X = 43 Y = 80

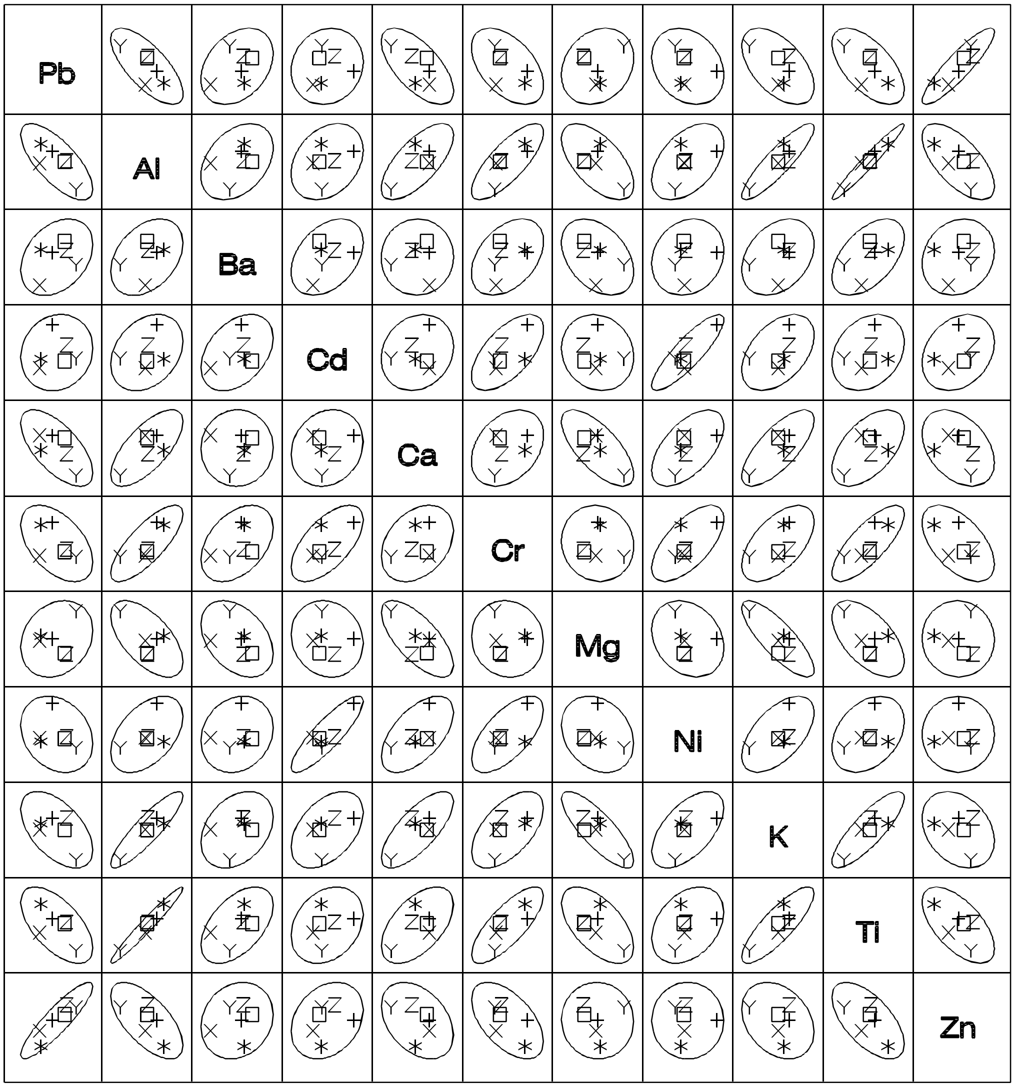
Figure 3e. Floor House Mean Correlation Scatterplot

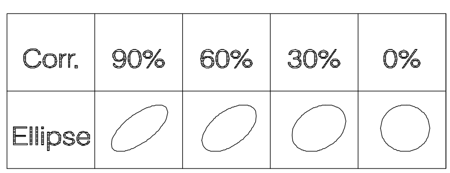


Corr.	90%	60%	30%	0%
Ellipse				

House Legend: *** = 17** **Q = 19** **+ = 33**
X = 43 **Z = 51** **Y = 80**

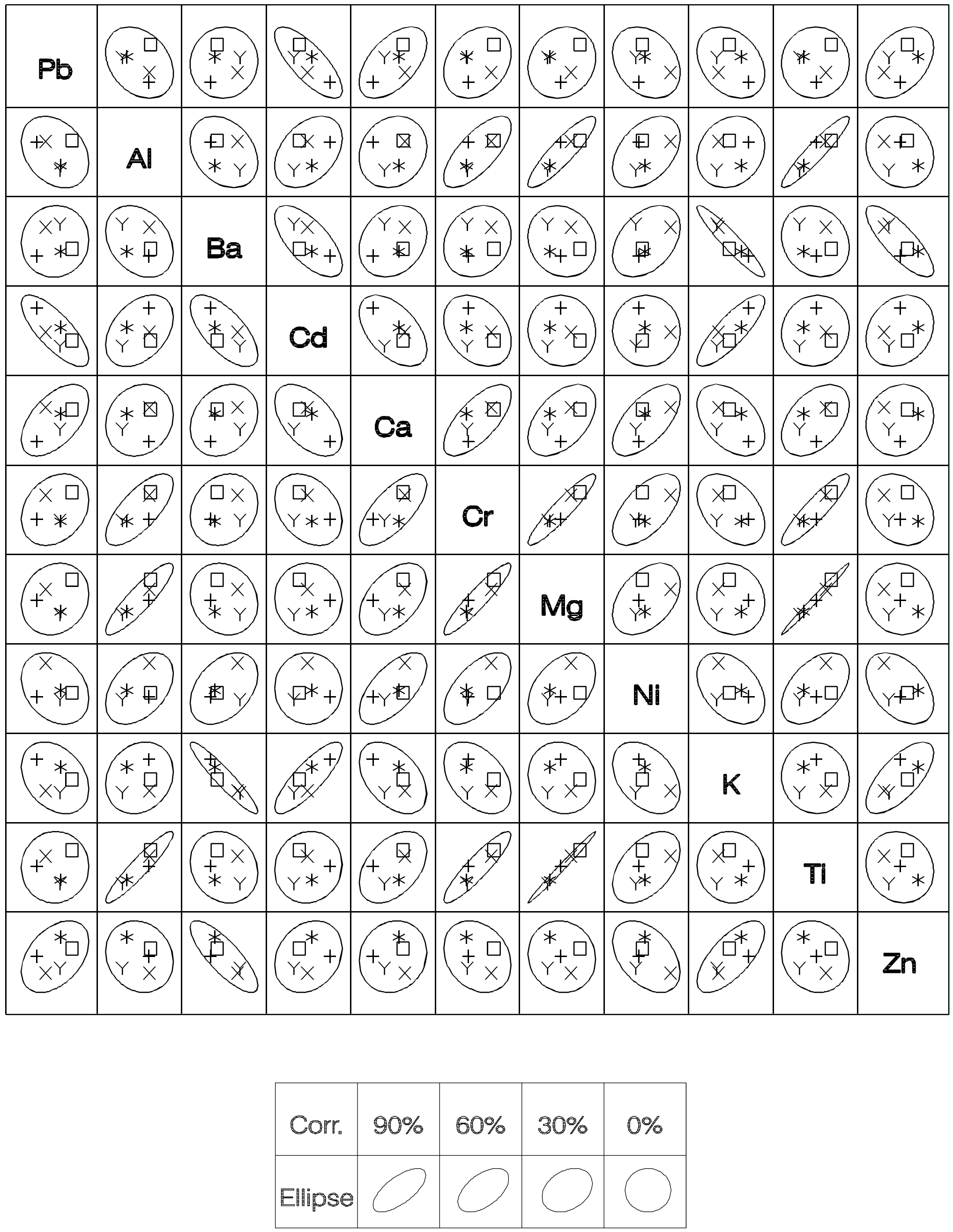
Figure 3f. Entryway Dust House Mean Correlation Scatterplot





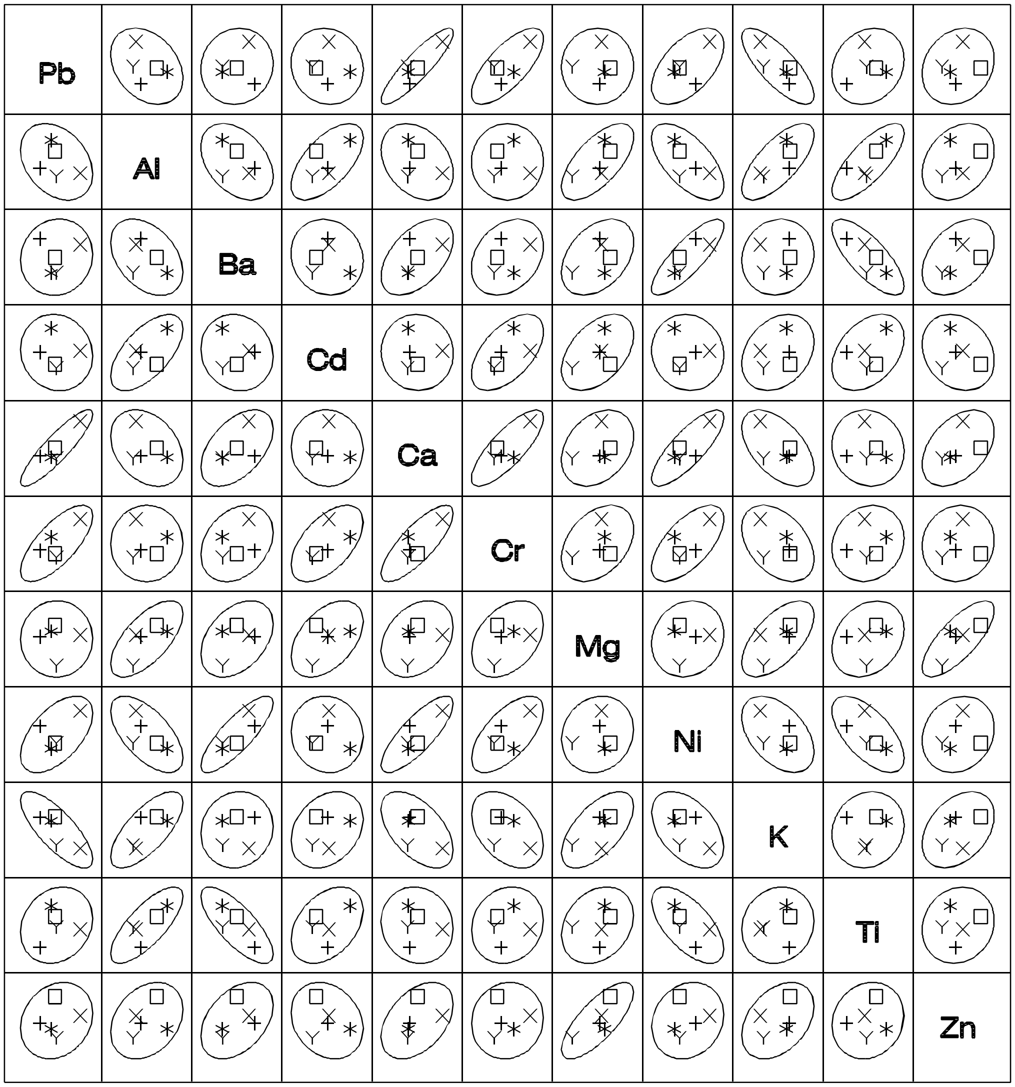
House Legend: *** = 17** Q = **19** + = **33**
X = 43 **Z = 51** **Y = 80**

Figure 3g. Entryway Soil House Mean Correlation Scatterplot



House Legend: * = 17 Q = 19 + = 33
X = 43 Y = 80

Figure 3h. Air Duct House Mean Correlation Scatterplot



Corr.	90%	60%	30%	0%
Ellipse				

House Legend: * = 17 Q = 19 + = 33
X = 43 Z = 51 Y = 80

Figure 3i. Bedcover/Rug/Upholstery House Mean Correlation Scatterplot

Air duct samples and bedcover/rug/upholstery samples had patterns that were unlike each other and the rest of the samples. Air duct samples were characterized by strong positive pairwise correlations between titanium, aluminum, chromium, and magnesium, and by a strong negative correlation between barium and potassium. Bedcover/rug/upholstery samples did not have the strong correlations seen for air ducts, but did have a pattern of positive correlations among lead, calcium, chromium, and nickel.

Because lead, barium, titanium, and zinc were used in paints in the past, the positive correlations among these elements for the window channel and window stool samples might be reflective of dust generated from paint.

2.3.3 Multivariate Relationships (Principal Components)

For the estimated model parameters displayed in Tables 6, 7, and 8 (average log-concentrations in unrenovated unabated houses, increments in log-concentration associated with renovation, and increments in log-concentration associated with abatement), a principal components analysis was performed across the nine sample types. The purpose of this analysis was to identify consistent patterns across sample types and to determine whether there were patterns in the differences between homes that were abated or renovated.

Principal component analyses can be performed based on either correlations or covariances. Analyses based on correlations standardize the range of each of the elements' concentrations. This prevents the most widely fluctuating elements from dominating the analysis and gives equal attention to all variables regardless of their range. Covariance-based analyses leave all element concentrations in their original scale. Since the scales observed varied substantially by element, and a priori there was no reason to weight more heavily the elements with greater absolute variation, correlations were used.

The numerical results of the principal components analyses and plots of the first two principal components are displayed in Table 10 and Figure 4. Table 10 displays estimates of the coefficients for the first two principal components followed by the cumulative proportion of total variation explained by these components. Figure 4 displays the relationship among the nine different sample types relative to the first two principal components. Although there are eleven elements, the two principal component axes represent the two perpendicular directions (in the eleven-dimensional space) in which the greatest variability was observed.

The first two principal components accounted for at least 68% of the total variability in the model parameter estimates in each of the three analyses. This means that although eleven elements were measured (lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc), most of the variation among the nine sample types occurred within a two-dimensional space (i.e., two linear combinations of the eleven element concentrations). In each case, this was highly significant.

In three of the principal components, aluminum and titanium both appear with negative coefficients. This is an interesting pattern because, as pointed out in Section 2.1, these two elements generally had higher concentrations in soil than dust, whereas all the other elements either were typically higher in dust than soil or had no significant differences across sample types.

Figure 4 shows that for averages in unrenovated, unabated houses it can be argued that the three soil sample types can be grouped into one cluster; floor, entryway, window stool, bedcover/rug/upholstery, and air duct dust sample types form another cluster; and window channels stand alone. This is similar to the groupings of Section 2.2 with one exception. In Section 2.2, air ducts stood alone, whereas here air ducts are grouped with a number of other sample types.

For the differences associated with renovated houses, all samples can be grouped into one cluster except for air ducts and bedcover/rug/upholstery, which are distinct from the rest of the samples and each other. This grouping has similarities to the grouping of Subsection 2.2. In that section, the three soil samples were grouped together, entryway and floor samples made up a second group, and it could be argued that the window channels and window stools should be grouped together. It is worth noting that the two sample types that did not fit into any group in either Figure 2b or Figure 4 (air ducts and bedcovers/rugs/upholstery) were not sampled in the only fully renovated house.

Table 10. Principal Components for Model Parameter Estimates (Adjusted House Averages, Abatement History, and Renovation History)

Response	Principal Component	Principal Component Coefficients[1]											Cumulative Explained Variability	Significance Level[2]
		Pb	Al	Ba	Cd	Ca	Cr	Mg	Ni	K	Ti	Zn		
Unrenovated Unabated Unit Means	1	0.20	-0.37	0.17	0.43	0.41	0.15	0.37	0.36	-0.09	-0.17	0.32	0.40	<0.001
	2	0.48	0.20	0.48	0.04	-0.00	-0.32	-0.00	-0.28	-0.27	0.43	0.25	0.71	
Abatement History	1	0.34	-0.37	0.30	0.11	0.07	-0.43	-0.43	0.16	0.09	-0.23	0.42	0.36	0.005
	2	0.35	0.29	0.31	0.31	-0.46	0.07	0.06	-0.34	0.10	0.44	0.22	0.68	
Renovation History	1	0.02	0.40	0.43	-0.13	0.03	0.46	0.34	0.30	-0.22	0.40	-0.10	0.43	<0.001
	2	0.47	-0.22	0.13	-0.15	0.40	-0.01	-0.15	0.33	-0.37	-0.23	0.45	0.83	

1. Coefficients are applied to the estimated parameters for each sample type to obtain maximum spread among sample types in two dimensions.
2. Significance level of the proportion of variability explained by the first two principal components under the null hypothesis of uncorrelated element concentrations. Under the null hypothesis, the distribution for the proportion of variability explained by the first two components was estimated based on a simulation study. The significance level is the probability that the proportion of variability explained by the first two components is larger than or equal to the observed proportion.

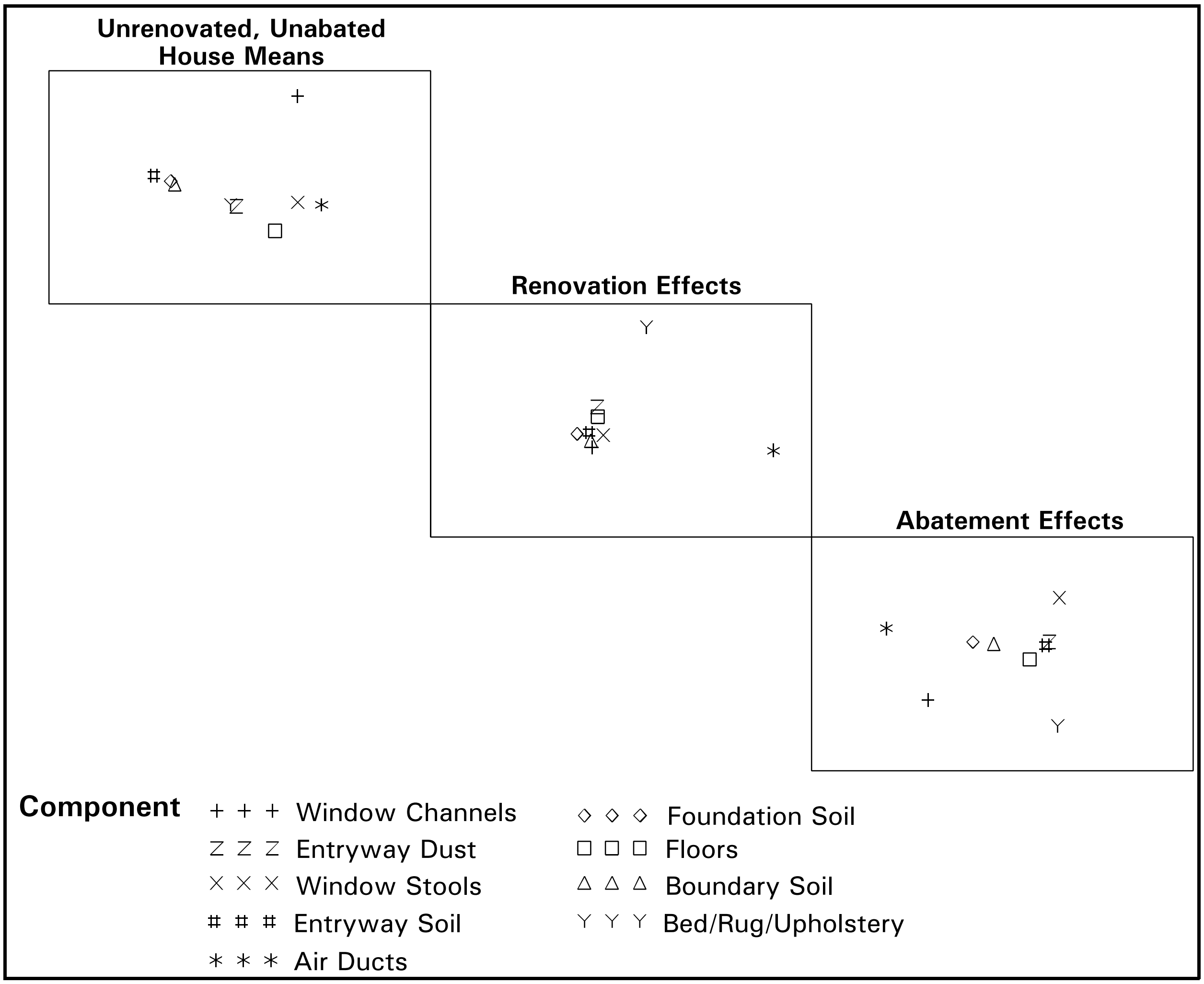


Figure 4. First Two Principal Components for Each Building Component, Plotted versus Each Other for Unrenovated, Unabated Unit Mean Log-Concentrations, Renovation History, and Abatement History

Figure 4 also displays differences associated with abated houses in the lower right hand corner of the figure. The foundation and boundary soil samples are close to each other, and nearby are floor, entryway dust, and entryway soil samples. Hence, for abatement, Figure 4 conveys far more clustering of sample types than does Figure 2c.

3.0 PEER REVIEW

This report was peer reviewed by four peer reviewers with expertise and background in the subject area of the report. Comments from the reviewers which had an important effect on the report and which are important for interpreting the report are described below.

One reviewer stated that the report was lacking in testable hypotheses. In response, testable hypotheses were added to the report. However, the report was intended to be an exploratory analysis in some respects and that exploratory aspect was retained. Another reviewer suggested an alternative graphical approach, which was incorporated into Figure 2 in the final report. The reviewer also suggested an ordering for graphs which produced monotonic plots that could be readily used as reference points for comparison. Significant changes were made to the description of the data in response to one of the reviewers. Reviewers also commented on the assumption of the lognormal distribution and the reliability of elemental measurements as could be measured by side-by-side samples. In response, sections on tests for lognormality and measurement reliability were added to Appendix A. Finally, in response to reviewer comments, the findings and conclusions of the report were reviewed and revised or replaced as necessary.

4.0 REFERENCES

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US EPA, 1995, “Comprehensive Abatement Performance Pilot Study, Volume I: Results of Lead Data Analyses”, EPA 747-R-93-007.

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APPENDIX A:

SUMMARY OF MULTI-ELEMENT DATA

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APPENDIX A:
SUMMARY OF MULTI-ELEMENT DATA

A-1.0 MULTI-ELEMENT DATA LISTING

Tables A-1a through A-1f contained the raw element concentration data for each of the six houses. Each table displays concentrations for a given house for each of the eleven elements by sample medium (dust or soil), sample type, location and sample ID. Each sample was uniquely identified by its house number and sample ID.

Table A-1a. CAP Pilot Study Multi-Element Data, House 17

Sample Identification				Concentrations (μg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Z
Dust	ARD	KIT	09	363	8970	187	16400	65.7	40.3	7740	3780	22.7	245	517[a]
		BD1	19	717	8660	173	16900	615	64.9	5790	3730	19.6	296	39900
	BRU	BD1	18	66.9	5140	434	19000	9.97	43.9	8100	3210	76.8	84.9	572
	EWY-I	EWY	20	282	10200	367	12300	19.6	36.5	8120	2290	27.3	285	426[a]
		EWY	21	259	10200	1100	16500	11.5	34.7	8420	3090	27.9	332	620[a]
	FLR	KIT	01	50.0	1690	742	14200	3.10	16.2	14400	2720	13.0	55.1	502
		KIT	03	254	6950	1840	23100	13.4	29.4	17200	3950	16.3	104	1340
		BD1	11	373	7290	742	15400	26.1	43.7	10000	2790	120	207	516[a]
		BD1	12	328	9280	875	8770	14.6	42.7	11500	2240	45.5	188	284[a]
		BD1	13	225	6090	698	33700	8.74	29.3	14900	4180	33.9	243	1750
		LVG	31	153	5170	442	13900	10.6	26.0	9870	2490	222	159	486[a]
		LVG	32	63.7	6460	165	7080	3.71	24.6	4600	1600	18.6	209	229[a]
	WCH	KIT	07	1140	268	915	22700	.[b]	45.0	481	4870	20.5	957	14900
	WST	KIT	06	221	6600	440	48000	114	23.6	31900	8460	159	323	1730
		BD1	14	727	16300	627	39100	198	35.8	3820	8040	23.1	552	10000
		BD1	16	338	12500	725	41700	191	38.6	4990	7360	22.2	368	4220
		LVG	36	506	4480	377	29700	39.5	42.9	8800	10900	188	243	2520
		LVG	39	270	12500	1820	21200	307	43.3	4920	3980	16.8	627	1310
		LVG	40	337	9770	2170	27200	146	50.8	6290	6380	27.1	505	1910[a]
Soil	BDY	LFT	26	52.2	26700	221	13100	2.68	44.6	6400	984	17.1	692	116
		BAC	27	70.5	20200	183	8260	2.33	38.5	5940	500	15.5	454	177
		LFT	28	56.4	25100	206	13300	2.61	43.8	5870	1030	16.4	643	108
	EWY-O	FRO	22	70.4	20400	196	12800	2.75	37.7	5360	540	15.1	486	181
		BAC	23	364	19600	440	14200	241	269	4570	614	238	582	499[a]
	FDN	LFT	24	70.2	20800	199	12200	2.81	40.9	5410	668	15.7	422	279
		BAC	25	69.4	18000	262	11300	2.62	39.2	4420	2570	13.9	391	345
		BAC	29	65.7	18200	171	11700	2.51	38.0	4460	2960	14.3	385	299

[a] Analysis result was greater than upper calibration limit; reported value is the maximum detectable concentration.
[b] Analysis result was greater than upper calibration limit for cadmium; sample excluded from data analysis.

Table A-1b. CAP Pilot Study Multi-Element Data, House 19

Sample Identification				Concentrations (μg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	LVG	09[b]	69.5	.	.	.	.	.	.	.	.	.	.
		BD1	19	624	8950	585	69600	23.7	146	3100	5100	313	351	1470
	BRU	LVG	08	482	6810	695	93800	12.7	187	1900	4600	389	265	1970
		BD1	18	485	2900	190	37000	8.51	81.4	1020	2430	112	104	341
	EWY-I	EWY	20	201	8660	275	140000	6.16	40.8	5400	6890	30.6	290	551
		EWY	21	184	6740	56.8	94800	10.1	40.1	2050	5990	47.6	241	583
	FLR	LVG	01	190	4560	179	177000	6.15	36.1	2890	7940	31.5	130	706
		LVG	03[b]	69.5	.	.	.	.	.	.	.	.	.	.
		BD1	11	301	5500	598	20000	19.5	114	2470	3370	152	157	683
		BD1	12[c]	.	.	.	.	.	.	.	.	.	.	.
		BD1	13	402	5690	831	58500	13.6	157	2140	3990	306	166	1520
		KIT	31	99.5	4250	103	9280	5.71	44.9	2290	2970	43.2	136	316[a]
		KIT	32	67.9	4330	53.1	8140	3.24	41.9	2270	2900	40.7	143	267[a]
	WCH	BD1	17[b]	368	.	.	.	.	.	.	.	.	.	.
	WST	LVG	04	70.8	4130	74.1	149000	4.14	50.3	1200	12400	19.1	416	231
		BD1	16	215	7760	281	74200	37.4	77.8	2450	4050	116	385	2050
		KIT	36	177	4190	209	92700	17.0	30.3	1690	2620	47.3	166	944
Soil	BDY	FRO	26	98.2	10900	121	8320	2.30	24.6	3430	430	8.91	379[d]	161
		LFT	27	43.3	8340	116	11200	2.30	16.0	3490	1510	6.58	257	107
		LFT	29	44.2	8030	110	11700	1.63	15.3	2950	1510	6.49	223	130
	EWY-O	FRO	22	49.7	12800	131	12200	2.27	23.7	3430	491	10.3	383	161
		BAC	23	40.4	9280	128	13400	2.04	17.9	2840	370	11.7	285	278
		FRO	28	197	31300	409	15100	3.23	34.3	6980	985	13.8	753	281
	FDN	FRO	24	49.2	10200	116	12600	2.02	19.7	3010	403	8.01	295	143
		LFT	25	238	10500	228	12500	4.85	27.8	3190	378	21.0	374	461

[a] Analysis result was greater than upper calibration limit; reported value is the maximum detectable concentration.
[b] ICP analysis hampered by calcium interference; no multi-element data reported.
[c] Sample dropped in laboratory; therefore, no data reported.
[d] The titanium concentration was originally reported as 0.38 μg/g. This concentration was flagged in the outlier analysis, investigated, and revised to 379 μg/g. The outlier analysis is described in Appendix B.

Table A-1c. CAP Pilot Study Multi-Element Data, House 33

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	BD2	09	477	8030	206	76700	19.8	53.0	3670	3380	27.7	297	2620
		LVG	19	1610	3550	225	36800	65.6	40.7	8410	2190	44.6	120	104000
	BRU	LVG	18	117	12000	163	18200	25.4	69.1	6720	3560	17.6	387	448
	EWY-I	EWY	20	128	21700	226	21000	12.9	94.2	5800	5180	21.5	572	458
		EWY	21	88.4	17900	298	15900	30.0	523	5830	3870	12.7	558	482
	FLR	BD2	01	135	4910	357	42300	13.1	96.7	1830	3250	33.5	165	426
		BD2	03	183	4880	139	41800	40.9	85.2	1210	2940	15.1	195	646
		LVG	11	189	13100	300	20800	88.9	180	5100	3170	18.6	389	939
		LVG	12	128	12400	453	21500	66.1	190	5710	2950	19.6	314	866
		LVG	13	107	13400	167	23900	20.8	146	5850	4060	22.9	325	608
		KIT	31	116	13600	288	19000	35.7	516	5990	3490	20.9	386	609
		KIT	32	88.2	13200	301	20200	33.0	676	5600	3670	16.8	355	577
	WST	BD2	04	575	7040	488	37300	19.6	135	5960	4150	52.2	625	1180
		LVG	14	175	9740	594	26900	24.7	101	3730	3220	21.5	373	1500
		LVG	16	562	8050	1830	55800	11.0	87.0	3350	4440	24.6	480	1610
		LDY	36	581	3960	510	155000	10.1	85.8	1510	6780	17.1	283	1180
	WCH	LVG	17	7240	13300	7060	34900	29.7	39.1	2560	4240	17.9	656	13800
Soil	BDY	LFT	26	44.1	10900	121	12000	2.18	27.0	2980	474	9.59	321	165
		FRO	27	168	13200	161	5270	2.01	19.9	3060	497	7.58	443	112
	EWY-O	FRO	22	63.2	22800	252	8130	2.52	29.4	4190	495	10.8	730	140
		BAC	23	136	26200	401	12500	14.4	952	6240	849	13.1	667	243
		FRO	28	57	21500	280	8090	1.75	26.9	3530	494	6.78	575	122
	FDN	LFT	24	167	22000	356	12400	3.51	31.3	4960	3060	15.9	423	258
		FRO	25	108	22700	309	12900	3.27	28.4	3620	616	11.9	601	263
		LFT	29	176	25500	369	12300	4.17	36.8	5540	3350	13.3	498	285

Table A-1d. CAP Pilot Study Multi-Element Data, House 43

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	LVG	09	1140	9150	243	63500	11.0	165	4100	6720	28.7	408	7810
		DIN	19[b]	611	.	.	.	.	.	.	.	.	.	.
	BRU	LVG	08	102	6500	209	28000	6.00	40.0	9200	3860	25.6	198	2990
		DIN	18	195	11500	304	22100	6.15	37.6	7770	4100	25.8	344	1250
	EWY-I	EWY	20	263	13400	331	18200	5.26	35.3	9790	4530	18.9	486	763
		EWY	21	589	14300	2110	23300	6.91	26.2	6060	4460	16.5	467	2070
	FLR	LVG	01	147	6600	220	15100	4.71	33.8	7020	2940	23.7	198	1640
		LVG	03	205	7830	288	43300	7.26	30.2	31700	8090	26.1	257	989
		DIN	11	234	6920	420	30100	7.73	51.5	8610	3720	44.9	231	2870[a]
		DIN	12	256	8630	393	21900	8.12	42.0	6270	3450	21.5	237	1160
		DIN	13	149	7490	210	15000	4.59	44.1	6800	2920	15.0	262	1320
		KIT	31	308	10400	873	17800	8.23	47.0	7390	3150	20.4	291	949
		KIT	32	309	13400	593	25000	8.79	45.6	6910	4430	61.5	422	981
	WST	LVG	04	964	5170	521	47400	18.2	82.7	4590	4450	25.3	440	1340
		DIN	16	378	10500	512	20200	20.6	28.6	6630	4020	17.5	312	6950
		KIT	36	397	9170	443	33800	221	44.3	3550	4210	22.6	353	1160
	WCH	LVG	05	963	13700	384	56400	8.93	23.8	5340	14000	17.3	509	2540
		KIT	38	1430	35400	367	13100	72.3	32.5	4640	4540	18.8	244	1720
Soil	BDY	FRO	26	290	12600	203	12500	4.53	28.3	4780	491	12.1	473	221
		BAC	27	60.8	5340	83.2	5790	0.94	13.8	1740	301	9.57	314	88.7
	EWY-O	FRO	22	623	13800	374	12100	6.58	28.7	3810	494	11.8	326	492[a]
		BAC	23	205	19400	374	13100	2.83	32.1	4550	506	11.7	741	300
		BAC	28	304	15700	284	13000	2.45	25.9	3880	493	10.8	497	272
	FDN	FRO	24	337	18500	460	10000	5.39	41.8	3800	3070	12.6	601	812
		BAC	25	181	21600	339	15800	3.80	36.4	4740	610	14.1	723	561
		FRO	29	245	19400	337	8240	4.29	34.6	3800	2410	12.0	577	488[a]

[a] Analysis result was greater than upper calibration limit; reported value is the maximum detectable concentration.
[b] ICP analysis hampered by calcium interference; no multi-element data reported.

Table A-1e. CAP Pilot Study Multi-Element Data, House 51

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	EWY-I	EWY	20	640	8490	234	130000	6.98	22.5	2320	7220	13.7	294	743
		EWY	21	4030	7110	75.5	127000	11.6	37.8	1630	7430	19.8	211	2760
	FLR	BAT	01	2450	4410	93.0	134000	8.78	20.7	1860	8590	36.0	149	3390
		BD3	11	966	6340	43.2	26400	7.50	25.8	2080	3010	15.3	188	966[a]
		BD3	12[b]	467	116	86.2	14800	1.72	5.59	815	1020	3.40	44.1	304
		BD3	13	712	5060	135	113000	5.30	16.8	1920	5590	13.5	175	782
		BD1	31	1780	5690	1430	91300	7.19	26.7	1690	3690	12.8	226	1440
		BD1	32	1760	6090	325	39300	6.44	22.9	2050	3140	11.9	260	1470[a]
		BD3	44	646	3290	27.0	17700	4.37	14.1	1760	2010	8.02	117	657[a]
	WST	BAT	06	6370	4020	679	154000	19.9	31.1	905	9290	165	259	4110
		BD3	14	774	7950	278	92300	4.73	22.9	2170	4730	90.4	345	835
		BD3	16	670	9160	314	77300	6.08	30.3	3110	4820	18.9	407	866
		BD1	40	3580	6950	746	77500	7.00	26.1	2780	5120	24.4	486	2170
	WCH	BAT	07	2730	4830	1190	123000	13.2	26.1	901	14500	52.5	362	3200
		BD3	15	421	13300	288	13500	6.71	33.6	3280	4390	22.0	485	753
		BD3	17	493	12500	300	15600	5.21	33.8	3410	4560	19.5	570	549
Soil	BDY	FRO	26	346	7760	207	5930	3.86	24.6	2220	304	11.2	306	314
		BAC	27	329	8190	177	6560	2.55	19.2	2600	1490	6.14	305	235
		BAC	29	300	7390	178	7070	2.40	16.9	2430	1690	5.83	271	217
	EWY-O	FRO	22	899	8710	232	4100	4.51	22.4	2290	1900	6.90	342	433
		BAC	23	505	9130	269	5800	3.74	23.1	2650	302	7.70	324	376
	FDN	FRO	24	938	9170	258	5450	4.13	15.9	1610	384	7.51	378	533
		BAC	25	539	9210	262	7960	3.81	22.5	2430	1520	7.10	343	377
		BAC	28	426	9320	257	7520	3.16	20.2	2310	295	6.90	346	340

[a] Analysis result was greater than upper calibration limit; reported value is the maximum detectable concentration.
[b] During initial sampling attempt, cartridge filled with sawdust prior to completion of sample collection. Sample was excluded from lead analysis and multi-element analysis.

Table A-1f. CAP Pilot Study Multi-Element Data, House 80

Sample Identification				Concentrations (μg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	BAT	09	1700	5810	1640	49700	6.65	84.0	2210	3760	37.6	225	5960
		BD3	19	965	5270	366	32200	7.79	78.8	3480	2280	12.4	209	1170[a]
		KIT	45	389	3610	470	13400	5.52	16.9	3420	1820	10.1	103	1240
	BRU	BAT	08	344	7780	263	41100	5.69	36.1	2510	2950	15.2	272	664
		BD3	18	66.3	2100	101	7620	4.79	33.3	1140	1180	42.5	117	136
	EWY-I	EWY	20	342	11800	303	25000	8.61	33.3	4990	3710	27.8	389	703
		EWY	21	222	7440	257	9620	4.00	28.9	670	2350	8.82	301	468
	FLR	BAT	01	1210	6870	1010	51000	5.37	31.2	3850	2990	14.6	226	1640
		BAT	03	649	8730	572	32800	4.37	32.4	4380	2860	18.5	198	1180
		BD3	11	180	3720	186	13900	9.25	46.1	3520	1510	51.2	155	436
		BD3	12	175	4810	176	18000	5.09	59.4	5050	1940	19.5	177	508
		BD3	13	243	6430	240	9710	5.33	44.3	3840	1720	14.8	224	326[a]
		KIT	31	182	4950	323	18200	4.23	25.4	2540	1890	10.6	239	436
		KIT	32	223	5510	350	15100	7.98	56.7	3840	2290	21.5	243	514
	WST	BAT	06	61600	610	30300	21300	30.8	151	1540	5080	42.4	181	35100
		BD3	14	680	6120	1380	38200	17.2	66.0	348	3160	99.3	426	1630
		PAN	36	535	5200	658	105000	7.85	60.1	2470	2740	15.9	630	2590
		KIT	39	7880	3830	29400	29300	23.3	104	745	2430	35.4	494	7560
		KIT	40	4660	6260	6560	45900	20.1	206	3150	2710	140	461	3470
	WCH	BD3	15	938	11600	846	51000	17.6	49.7	3340	5030	15.6	439	1850
		KIT	41	4550	8140	22500	65400	23.1	94.8	959	4060	21.5	715	4830[a]
		KIT	42	5790	11400	10900	29500	30.4	97.7	1810	3750	147	568	4510[a]
Soil	BDY	FRO	26	308	13000	246	8320	9.30	24.0	4220	489	9.51	437	394
		BAC	27	343	13400	279	7260	6.19	24.8	4660	493	11.0	326	396
	EWY-O	FRO	22	380	16400	282	6960	9.88	31.3	4970	489	12.3	486	385
		BAC	23	350	15200	288	10500	7.69	31.9	4710	502	11.5	501	417
		BAC	28	412	17600	340	8230	8.29	31.8	5220	487	13.8	528	492[a]
	FDN	LFT	24	942	17300	414	6940	14.0	32.9	4440	772	13.8	564	973
		BAC	25	459	8810	202	5160	6.06	23.0	2470	1510	7.43	322	345
		BAC	29	317	8890	198	7430	7.56	23.8	2570	1500	8.05	288	377

[a] Analysis result was greater than upper calibration limit; reported value is the maximum detectable concentration.

A-2.0 GEOMETRIC MEAN CONCENTRATIONS BY SAMPLE TYPE AND UNIT

House geometric mean concentrations of the eleven elements were the basic quantities used in the statistical analyses. They are listed in Table A-2. Also included in Table A-2 are indicators of interior and exterior abatement for each house. A “U” indicates that no abatement was performed in the house, an “R” indicates that the house was abated primarily by removal methods, and an “E” indicates that the house was abated primarily by encapsulation/enclosure methods. Table A-2 also contains the number of samples for which concentrations were determined for all eleven elements. Any sample in Table A-1a through A-1f for which at least one element had a missing value was not included in the calculations for the Table A-2 summary.

Table A-2. Geometric Mean Concentration by Sample Type and Unit

Sample Type	House	Interior Abatement History	Exterior Abatement History	Renovation	Samples Taken in Unit	Geometric Mean Concentrations (μg/g)										
						Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
WCH	33	U	U	None	1	7238.3	13345.9	7057.8	34866.1	29.66	39.05	2563.4	4237.1	17.86	655.7	13782.9
	43	R	R	None	2	1174.9	22025.3	375.5	27181.3	25.40	27.82	4977.4	7979.5	18.02	352.5	2089.1
	51	E	R	Full	3	827.6	9305.9	469.3	29601.8	7.73	30.92	2158.1	6625.4	28.21	464.2	1097.5
	80	E	E	None	3	2913.6	10248.9	5915.2	46139.1	23.09	77.22	1794.5	4244.4	36.69	563.0	3426.6
WST	17	R	E	None	6	368.3	9505.7	817.6	33201.3	140.20	38.12	7410.0	7191.9	43.74	414.4	2781.5
	19	U	U	Partial	3	139.2	5120.0	163.3	100782.1	13.80	49.10	1708.4	5090.4	47.15	298.3	765.2
	33	U	U	None	4	425.4	6836.3	721.8	54305.9	15.22	100.43	3260.0	4478.2	26.21	422.0	1354.3
	43	R	R	None	3	525.1	7928.2	490.7	31861.3	43.54	47.14	4764.2	4222.3	21.50	364.5	2212.6
	51	E	R	Full	4	1854.4	6718.3	458.6	96019.2	7.96	27.40	2030.3	5742.0	51.21	364.8	1594.7
	80	E	E	None	5	3828.3	3416.5	5556.1	40917.9	18.10	105.18	1254.4	3105.9	50.58	406.3	5223.5
ARD	17	R	E	None	2	510.6	8813.8	179.9	16615.1	201.09	51.14	6695.5	3759.1	21.10	269.7	4537.5
	19	U	U	Partial	1	624.4	8948.0	585.1	69610.2	23.72	145.95	3097.1	5103.5	312.90	351.4	1465.9
	33	U	U	None	2	874.6	5340.9	215.5	53114.2	36.02	46.41	5553.4	2719.4	35.15	188.4	16503.7
	43	R	R	None	1	1137.7	9152.4	243.1	63535.5	11.03	164.75	4100.3	6724.6	28.70	408.4	7806.0
	80	E	E	None	3	861.2	4800.0	655.5	27795.2	6.59	48.20	2971.9	2497.4	16.77	169.6	2053.8
FLR	17	R	E	None	7	165.5	5548.9	642.6	14686.3	9.17	28.83	10974.0	2726.5	39.95	151.1	568.7
	19	U	U	Partial	5	173.1	4830.6	217.4	27470.5	7.87	65.56	2398.4	3911.9	76.26	145.9	573.1
	33	U	U	None	7	130.7	9921.4	267.2	25622.3	35.89	203.43	3854.7	3341.5	20.42	290.5	647.6
	43	R	R	None	7	220.9	8504.5	380.0	22451.7	6.86	41.41	8828.0	3844.8	27.29	264.2	1310.1
	51	E	R	Full	6	1227.1	5024.0	137.8	54204.6	6.43	20.63	1890.0	3870.5	14.44	179.6	1235.2
	80	E	E	None	7	304.8	5668.4	338.8	19605.1	5.71	40.40	3789.6	2109.9	19.03	206.6	609.7
BRU	17	R	E	None	1	66.9	5139.3	433.8	19032.9	9.97	43.85	8097.0	3210.0	76.84	84.9	572.3
	19	U	U	Partial	2	483.3	4444.6	363.7	58943.0	10.41	123.27	1395.4	3342.6	208.42	166.3	819.4
	33	U	U	None	1	116.9	11954.3	162.5	18229.9	25.44	69.06	6723.0	3558.3	17.55	387.4	447.8
	43	R	R	None	2	141.3	8630.5	252.1	24888.9	6.07	38.78	8456.8	3977.0	25.69	260.9	1931.2
	80	E	E	None	2	151.1	4040.3	163.2	17692.3	5.22	34.67	1688.3	1867.1	25.43	178.7	300.7
EWY-I	17	R	E	None	2	269.9	10232.5	636.0	14240.0	14.99	35.56	8268.5	2659.3	27.59	307.6	513.8
	19	U	U	Partial	2	192.6	7640.8	125.0	114992.3	7.88	40.40	3326.8	6423.5	38.19	264.3	566.6
	33	U	U	None	2	106.4	19721.0	259.4	18226.2	19.71	221.98	5812.2	4477.7	16.55	565.2	469.9
	43	R	R	None	2	394.0	13844.0	835.8	20562.2	6.03	30.42	7701.6	4497.6	17.63	476.5	1255.7
	51	E	R	Full	2	1605.4	7773.1	133.0	128563.4	9.00	29.12	1944.0	7325.5	16.46	249.1	1432.1
	80	E	E	None	2	275.4	9357.4	279.1	15521.7	5.87	30.99	1828.9	2953.4	15.66	341.8	573.6

U = unabated, R = removal, and E = encapsulation/enclosure.

Table A-2. (Continued)

Sample Type	House	Interior Abatement History	Exterior Abatement History	Renovation	Samples Taken in Unit	Geometric Mean Concentrations (μg/g) Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
EWY-O	17	R	E	None	2	160.1	19994.7	293.5	13488.9	25.75	100.69	4950.2	575.9	59.90	532.3	300.2
	19	U	U	Partial	3	73.3	15510.8	190.1	13527.8	2.46	24.38	4083.4	563.6	11.83	434.5	232.7
	33	U	U	None	3	78.8	23437.0	304.8	9360.6	3.99	90.97	4517.1	591.9	9.85	654.3	160.7
	43	R	R	None	3	338.4	16152.0	341.1	12687.1	3.57	28.76	4069.0	497.6	11.39	493.4	342.3
	51	E	R	Full	2	673.7	8916.5	249.5	4876.6	4.11	22.75	2461.6	757.7	7.29	333.0	403.5
	80	E	E	None	3	379.6	16376.5	302.3	8453.0	8.57	31.68	4962.2	492.6	12.51	504.5	429.4
FDN	17	R	E	None	3	68.4	18939.6	207.4	11734.0	2.64	39.32	4740.2	1718.7	14.63	398.8	306.6
	19	U	U	Partial	2	108.3	10368.0	162.2	12527.0	3.13	23.43	3096.0	390.2	12.96	331.9	257.1
	33	U	U	None	3	146.9	23354.5	343.9	12542.9	3.63	31.99	4632.8	1848.8	13.59	502.1	268.6
	43	R	R	None	3	246.0	19783.7	374.5	10929.7	4.45	37.50	4092.1	1652.2	12.88	630.4	605.7
	51	E	R	Full	3	599.4	9231.2	259.0	6884.4	3.68	19.34	2081.4	556.2	7.17	355.5	408.9
	80	E	E	None	3	515.4	11057.3	254.5	6432.2	8.62	26.19	3045.3	1204.9	9.38	374.2	502.1
BDY	17	R	E	None	3	59.2	23827.4	202.5	11296.0	2.54	42.19	6063.7	797.2	16.32	587.0	130.4
	19	U	U	Partial	3	57.3	9015.6	115.6	10270.8	2.05	18.17	3280.7	993.6	7.25	278.8	131.0
	33	U	U	None	2	86.0	11982.1	139.7	7961.7	2.09	23.19	3019.1	485.7	8.53	377.2	135.6
	43	R	R	None	2	132.6	8192.7	130.0	8519.8	2.06	19.74	2880.7	384.3	10.77	385.3	140.1
	51	E	R	Full	3	324.7	7773.8	186.7	6504.0	2.87	19.98	2413.1	914.8	7.37	293.8	252.1
	80	E	E	None	2	324.8	13198.4	261.9	7770.7	7.59	24.40	4435.5	491.3	10.25	377.5	395.2

U = unabated, R = removal, and E = encapsulation/enclosure.

APPENDIX B:

DISTRIBUTION AND OUTLIER ANALYSIS FOR THE CAPS PILOT MULTI-ELEMENT DATA

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APPENDIX B:
DISTRIBUTION AND OUTLIER ANALYSIS

B-1.0 INTRODUCTION

This appendix documents an analysis leading to the selection of the lognormal distribution for characterizing element concentrations, provides a quantification of the reliability of the element concentrations measured for this report, and presents the statistical outlier analysis performed on the CAPS Pilot multi-element data. The statistical approach employed, the outliers identified, and the results of the laboratory review of the outlier data are discussed.

B-2.0 LOGNORMAL ASSUMPTION

To investigate the appropriateness of the lognormal assumption, a goodness-of-fit test was applied. The results of this test are presented in Table B-1. For each element and each component sampled, a Shapiro-Wilk goodness of fit test was applied to both the untransformed and the log-transformed concentrations. A 'Yes' appears in Table B-1 for each case where the hypothesis of normality is rejected at the 0.05 level, and a 'No' is for the case where hypothesis of normality is not rejected.

Of the 99 element-component combinations examined, there were 42 cases where neither untransformed data nor log-transformed data were rejected as non-normal. There were 32 cases where the untransformed data were rejected as non-normal while the log-transformed data were not rejected as non-normal. On the other hand, there were only 3 cases in which the log-transformed data were rejected as non-normal and the untransformed data were not rejected. There were 22 cases rejected for non-normality of both the log-transformed and untransformed data. Overall, for approximately 75% of the tests, the lognormal distribution was not rejected, whereas for approximately 45% of the tests, the normal distribution was not rejected. Hence the lognormal distribution was chosen over the normal distribution for the analysis of the data.

When interpreting these results, however, it is important to remember that these tests do not control for systematic differences between observations. For example, differences between abated and unabated homes and substrate effects are not adjusted for. The tests are also based on very little data (sample size for each element-component combination is no more than 6). Thus, this should only be regarded as a cursory analysis, leading to a decision regarding whether or not to transform the data before modeling. It is not a full-fledged declaration that the variability in these elements is well characterized by the lognormal distribution.

Table B-1. Test of Normality: Log-transformed and Untransformed Data[a]

Elements	Dust						Soil		
	ARD	BRU	EWI	FLR	WSL	WST	BDY	EWY	FDN
Aluminum	Yes/No	No/No	No/No	No/Yes	Yes/No	No/Yes	No/Yes	No/No	Yes/Yes
Barium	No/Yes	No/No	No/Yes	No/Yes	Yes/Yes	No/Yes	No/No	No/No	No/No
Calcium	No/No	No/Yes	Yes/Yes	Yes/Yes	No/Yes	No/No	No/No	Yes/No	No/No
Magnesium	No/No	No/No	No/No	Yes/Yes	No/Yes	Yes/Yes	Yes/Yes	Yes/Yes	No/Yes
Nickel	No/Yes	No/Yes	No/No	Yes/Yes	Yes/Yes	Yes/Yes	No/No	Yes/Yes	No/No
Potassium	No/No	No/No	No/No	No/Yes	No/Yes	No/No	No/No	No/No	No/No
Cadmium	No/Yes	No/Yes	No/Yes	Yes/Yes	Yes/Yes	No/Yes	No/Yes	Yes/Yes	No/Yes
Chromium	No/No	No/Yes	Yes/Yes	Yes/Yes	No/Yes	No/Yes	No/Yes	Yes/Yes	No/No
Lead	No/No	No/No	Yes/Yes	No/Yes	Yes/Yes	No/No	Yes/Yes	No/No	No/Yes
Titanium	No/No	No/No	No/No	No/No	No/No	No/No	No/No	No/No	No/No
Zinc	No/Yes	No/No	Yes/Yes	No/Yes	No/Yes	No/Yes	No/Yes	No/No	No/Yes

[a] Test results are presented first for log-transformed data and then for untransformed data. Yes indicates the hypothesis of normality was rejected. No indicates the hypothesis of normality was not rejected.

B-3.0 CHARACTERIZATION OF MEASUREMENT RELIABILITY

Side-by-side dust samples were collected on floors and window stools. Eleven pairs were collected on floors, and two pairs were collected on window stools. Side-by-side soil samples were also collected near entryways, foundations, and property boundaries. These allow characterization of the degree of variability introduced by local spatial variability combined with the variability introduced by the chemical analysis process. Table B-2 provides estimates of the log standard deviation of measured concentration in side-by-side samples for each of the eleven elements considered. Also provided is an estimate of the proportion of total variability that is attributed to real variation in element concentrations. This is measured as the total variance minus the variance of side-by-side measures, divided by the total variance. This quantity is labeled as the measurement reliability. The closer this quantity is to 1, the more reliable the measurement.

Table B-2. Log Standard Deviation and Measurement Reliability of Measured Concentrations in Side-By-Side Dust Samples Collected from Floors and Window Stools

Elements	Floor		Window Stool		Soil	
	Log Standard Deviation[a]	Measurement Reliability[b]	Log Standard Deviation	Measurement Reliability	Log Standard Deviation[a]	Measurement Reliability[b]
Aluminum	0.18	0.86	0.28	0.78	0.27	0.68
Barium	0.44	0.84	0.76	0.74	0.34	0.43
Cadmium	0.37	0.86	0.38	0.93	0.16	0.89
Calcium	0.30	0.77	0.26	0.61	0.10	0.88
Chromium	0.24	0.94	0.35	0.81	0.13	0.78
Magnesium	0.18	0.73	0.24	0.76	0.51	0.45
Nickel	0.70	0.57	0.73	0.61	0.17	0.78
Lead	0.25	0.93	0.29	0.97	0.42	0.84
Potassium	0.22	0.88	0.73	0.63	0.22	0.72
Titanium	0.16	0.84	0.11	0.58	0.24	0.60
Zinc	0.30	0.81	0.43	0.76	0.18	0.90

[a] Log standard deviation is the square root of the variance of the log-transformed concentrations due to the side-by-side measurement error.

[b] The measurement reliability is the proportion of the total variance not attributed to side-by-side measurement error. It characterizes the precision of the measurements.

Measurement reliability was above 70% for 17 of the 22 element measures for dust. It was above 70% for 7 of the 11 elements in soil. The lowest reliabilities, 0.43 and 0.45, were observed for soil measurements of barium and magnesium, respectively.

B-4.0 OUTLIER ANALYSIS

Two outlier tests were applied to the multi-element data. The first was a univariate outlier test, which evaluates one element at a time. This is the same test that was previously applied to the lead data. The test was applied to the natural logarithms of the concentrations for lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc. The second test was a multivariate outlier test, which evaluates measurements for all eleven elements simultaneously. The multivariate test detects measurements which for a single element may not be an outlier, but when viewed in combination with the other elements is inconsistent with the majority of the data. Groupings of the data were defined before performing the outlier tests.

B-4.1 DATA GROUPING

The following homogeneous groups of data were identified for each indicated sample type:

- Vacuum Cassette Samples (7 groups): air duct, upholstery (including bed coverings and throw rugs), interior entryway, floor (excluding entryway), window stool, window channel, and floor (including entryway);

- Soil Samples (4 groups): boundary, foundation, exterior entryway, and all exterior samples combined.

Initially, data for all six units in the Pilot Study were combined before performing the univariate and multivariate outlier tests on these groups. When there were sufficient data, subsequent univariate outlier tests were also performed by segregating the data in each group by abatement method and by housing unit. Segregating by abatement method and unit was not done for the multivariate test due to the need for larger sample sizes with the increase in dimensionality.

B-4.2 UNIVARIATE OUTLIER TEST

Formal statistical outlier tests were performed on the natural logarithms of the concentrations for lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium and zinc. Data were placed into groups of comparable values, and a maximum absolute studentized residual procedure was used to identify potential outliers. The

SAS procedure GLM (SAS PC, ver. 6.08) was used to compute the studentized residual for each data value in a group by fitting a "constant" model (i.e., mean value plus error term) to the log-transformed data in each group. The absolute values of the studentized residuals were then compared to the upper .05/n quantile of a student-t distribution with n-2 degrees of freedom, where n is the number of data values in the group. If the maximum absolute studentized residual was greater than or equal to the .05/n quantile, the corresponding data value was flagged as a potential outlier. When a potential outlier was identified, that value was excluded from the group, and the outlier test was performed again. This procedure was repeated until no more outliers were detected.

B-4.3 MULTIVARIATE OUTLIER TEST

The multivariate outlier test is based on the Hotelling T-squared statistic, with one major difference. The Hotelling T-squared statistic is discussed in most multivariate statistics texts. The difference in the statistic used here is that, in computing the statistic for the i^{th} observation, that observation is excluded from the computation of the mean vector and the variance-covariance matrix. This yields estimates of location and covariance that are unaffected by the observation in question and lead to a more robust outlier test. This is a multivariate extension of the univariate studentized residual used for the univariate outlier test. Under assumptions of normality, the resulting statistic has an F distribution, with numerator degrees of freedom equal to p (the number of elements) and denominator degrees of freedom equal to a function of p and the sample size, N. In this case, p was equal to eleven.

The observation corresponding to the maximum value of the statistic in a data group was declared a potential outlier if the statistic exceeded the (1-.10/N) quantile of the F distribution with appropriate degrees of freedom. When a potential outlier was identified, that sample was excluded from the group, and the outlier test was performed again. This procedure was repeated until no more outliers were detected.

B-4.4 RESULTS OF OUTLIER ANALYSIS

The potential outliers identified by these two tests were screened by a statistician to eliminate those that were merely numerical anomalies due to very small sample sizes. The remaining outliers identified by the univariate test are listed in Table B-3, and those identified by the multivariate test are listed in Table B-4. These lists of the remaining outliers were sent back to the laboratory for verification. One outlier was confirmed by the laboratory as an error and is documented in the footnote to Table A-1b. All remaining outliers were verified and declared by the laboratory to be correct as reported.

Table B-3. Univariate Outliers Detected by Univariate Methods

Sample Processing Batch	House ID/ Sample ID	Concentration (μg/g)* Al	Ba	Cd	Cr	Ni	Ti	Zn
CLS	33/20				94.18			
CRS	33/21				523.19			
SSS	33/23			14.43	951.74			
CSS	33/31				515.97			
CSS	33/32				676.48			
SSS	43/22			6.58				
SSS	43/26			4.53				
SSS	43/27			0.94	13.75			
CSS	43/11							2866.97
CSS	43/32						422.12	
CKC	43/36			220.60				
CKC	17/01				16.00		55.00	502.00
CLS	17/03						104.36	
SSS	17/23			241.07	268.94	238.11		
CLS	19/04							231.35
CLS	19/08				186.60			
CLS	19/13							1520.83
SSS	19/25			4.85				
SSS	19/26						0.38	
CLS	17/19			615.27				
SKI	43/24			5.39				
SSS	19/28						753.13	
CLS	19/36						165.58	
CRS	80/06	609.89	30315.04				181.30	35121.27
SSS	80/24			13.98			564.27	972.71
SSS	80/26			9.30				
SSS	80/27			6.19				
CLS	80/09							5963.48
CLS	80/45				16.92			
CSS	80/39		29402.19					
CSS	80/41		22466.22					
CRS	51/12			1.72	5.59		44.14	
CLS	51/20				22.45			
SSS	51/24							533.06
SSS	51/26			3.86				
CRS	33/19				99.07			
CRS	43/16							306.14

* No outliers were detected for calcium, magnesium, lead and potassium.

Table B-4. Outliers Detected by Multivariate Methods

Sample Processing Batch	House	Sample ID	Concentration (μg/g)										
			Pb	Al	Ba	Cd	Ca	Cr	Mg	Ni	K	Ti	Zn
CLS	17	03	253.91	6949.83	1841.07	13.39	23113.58	29.35	3950.11a	16.27	17158.68	104.36a	1338.25
CKC	17	01	50	1694	742	3.1	14246	16.19	2724	13	14419	55.07	502
CRS	80	06	61573.85	609.89	30315.04	30.83	21251.35	151.36	5080.89	42.43	1536.03	181.3	35121.27
SSS	51	26	345.81	7761.56	206.56	3.86	5934.11	24.57	303.99	11.18	2224.18	306.4	313.77
SSS	17	23	363.88	19585.58	439.75	241.07	14160.18	268.94	614.15	238.11	4570.6	582.48	499.30
SSS	33	23	135.78	26178.44	401.46	14.43	12471.77	951.74	848.89	13.06	6241.22	667.37	243.15

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11. SUPPLEMENTARY NOTES

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13. ABSTRACT (Maximum 200 words)

This report presents the results of the statistical analysis of multi-element data collected during a pilot study that preceded the Comprehensive Abatement Performance (CAP) Study. The goal of the CAP Study was to assess the long-term efficacy of lead-based paint abatement. In this report, multi-element analysis was undertaken to determine whether relationships among lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc in dust and soil samples could provide a way to identify the source and pathways of lead in households. This report summarizes the results of the investigation of the multi-element analysis.

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